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Kraft Pulp Industry Particulate Emissions Source Category Report

Acurex Corp., Mountain View, CA

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Sulfate Pulping	Stationary Sources	13H, 07A
Emission	Kraft Pulp Mills	14G
Particles	Particulate	
Aerosols	Emission Factors	07D
Wood Pulp		11L

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KRAFT PULP INDUSTRY PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT

by

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ABSTRACT

The objective of this study was to develop particulate emission factors based on cutoff size for inhalable particles for the kraft pulp industry. After a review of available information characterizing particulate emissions from kraft pulp mills, the data were summarized and rated in terms of reliability. Size specific emission factors were developed from these data for the major processes used in the manufacture of kraft pulp. A detailed process description was presented with emphasis on factors affecting the generation of emissions. A replacement for Section 10.1 (Chemical Wood Pulping) of EPA report AP-42, A compilation of Air Pollutant Emissions Factors, was prepared, containing the size specific emission factors developed during this program.

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SECTION 1
INTRODUCTION

This document is a source category report on inhalable particulate matter emitted by the kraft pulp industry. Inhalable particulate matter can be characterized as particles of respirable size capable of reaching the lower lung.

The source category report summarizes available data on inhalable particulate emissions from sources typical of the industry. The main objectives of this are:

- To develop reliable total and size specific particulate emission factors for controlled and uncontrolled emissions for each emission source in the kraft pulp industry
- To summarize existing data on chemical characterization of inhalable particulate emissions
- To update Section 10.1.2 "Kraft Pulping" in AP-42 Compilation of Air Pollutant Emission Factors, with the size specific emission factors developed during this study. (Sections 10.1.3 "Acid Sulfite Pulping" and 10.1.4 "Neutral Sulfite Semichemical (NSSC) Pulping" were not revised.)

These objectives were met by an intensive literature search and through personal contact with individuals and organizations known to be familiar with the kraft pulp industry. The individuals and organizations are listed in Appendix A. Sources for data include:

- DIALOG computerized literature searches
- Control agencies
    - -- U.S. Environmental Protection Agency
    - -- State and local air pollution control agencies
    - -- Canadian Air Pollution Control Directorate

- Trade organizations
    - National Council of the Paper Industry for Air and Steam Improvement (NCASI)
    - Technical Association of the Pulp and Paper Industry (TAPPI)
- Industry contacts
    - Kraft pulp industry
    - Vendors of control equipment for the kraft pulp industry
- AP-42 kraft pulp mill background file at the Office of Air Quality Planning and Standards (OAQPS)
- EPA's Fine Particle Emission Information System (FPEIS)

Particle sizes are usually expressed in terms of the aerodynamic diameter (see Glossary of Terms). This method of size expression is useful because it is readily determined through straightforward measurement where the other properties of actual particle size and density may not be obtainable.

There are two general classifications of particle size measurement systems, 1) inertial separation and, 2) optical or electrical mobility measurement. The majority of all particle sizing currently performed in source testing uses equipment based on inertial separation. Data in this report are the result of measurements using either of two inertial instruments, the Southern Research Institute (SoRI) two-cyclone train or the cascade impactor.

The SoRI two-cyclone train is a system consisting of two cyclones and a filter in series which is used as the primary system to determine the total particulate concentration, the inhalable particulate concentration (≤ 15 µm), and the fine particulate concentration (≤ 2.5 µm). The train is shown schematically in Figure 1-1.

The cascade impactor is a low-speed impaction device consisting of pairs of jets (each of progressively smaller size) and sampling plates. It is designed so that each plate collects particles of one size range expressed as d_{50}, the particle size in microns for which 50 percent of the particles are theoretically collected on a particular sampling plate or stage. The cross section of a Mark III cascade impactor is shown in Figure 1-2.

The data which were obtained were reviewed, analyzed, and ranked according to the criteria provided in the report "Technical Procedures for

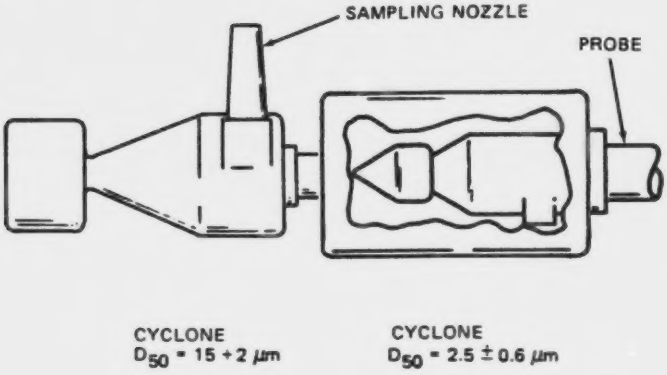

SAMPLING NOZZLE
PROBE
CYCLONE
D_{50} = 15 + 2 μm
CYCLONE
D_{50} = 2.5 ± 0.6 μm

Figure 1-1. Schematic of the SoRI two-cyclone train.

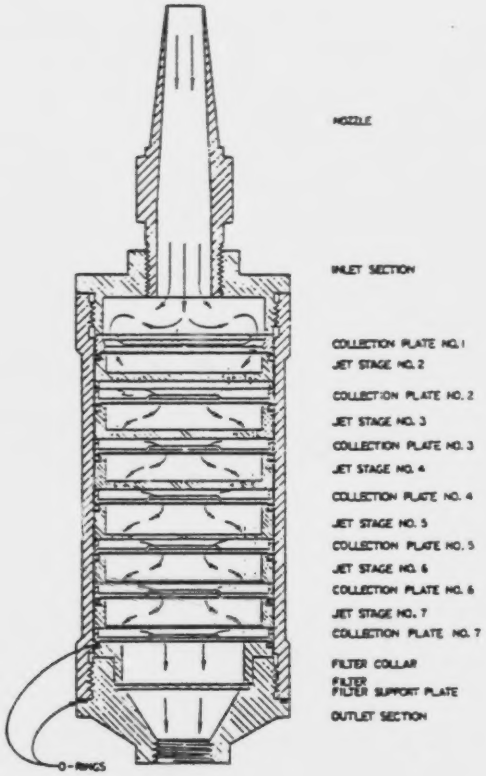

NOZZLE
INLET SECTION
COLLECTION PLATE NO. 1
JET STAGE NO. 2
COLLECTION PLATE NO. 2
JET STAGE NO. 3
COLLECTION PLATE NO. 3
JET STAGE NO. 4
COLLECTION PLATE NO. 4
JET STAGE NO. 5
COLLECTION PLATE NO. 5
JET STAGE NO. 6
COLLECTION PLATE NO. 6
JET STAGE NO. 7
COLLECTION PLATE NO. 7
FILTER COLLAR
FILTER
FILTER SUPPORT PLATE
OUTLET SECTION
O-RINGS

Figure 1-2. Cross section of Mark III cascade impactor.

Developing AP-42 Emission Factors and Preparing AP-42 Sections" April 1980.[1-1] If there was no reason to exclude particular data from consideration, each data set was assigned a ranking. The data were ranked as follows:

A -- Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.

B -- Tests performed by a generally sound methodology but lacking enough detail for adequate validation

C -- Tests based on an untested or new methodology or lacking a significant amount of background data

D -- Tests based on a generally unacceptable method but which may provide an order-of-magnitude value for the source

Upon ranking the data, a single emission factor was calculated. The reliability of this emission factor is indicated by an Emission Factor Rating. The ratings are subjective quality evaluations rather than statistical confidence intervals and range from A (excellent) to E (poor) as follows:

A -- Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category* is specific enough to minimize variability within the source category population.

B -- Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A rating, the source category is specific enough to minimize variability within the source category population.

C -- Average. Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

---

*Source category: A category in the emission factor table for which an emission factor has been calculated; generally a single process.

D -- Below average. The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E -- Poor. The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

Process and control system operating data were obtained and summarized. Cyclic or other peculiarities which may affect emissions were identified and presented in both the kraft pulp industry description section and in the proposed AP-42 section. Because of the nature of AP-42, certain duplication of information occurs in Sections 1 through 4 and Section 5 of this report.

References for Section 1

1-1. Compilation of Air Pollutant Emission Factors, Third Edition, U. S. Environmental Protection Agency, AP-42, April 1981.

SECTION 2
KRAFT PULP INDUSTRY

2.1 GENERAL

Pulping is the conversion of fibrous raw materials such as wood, used paper, or cotton into a material (i.e., a pulp) that can be converted into paper, paperboard, and building materials. The principal source of these fibers is wood, and the fiberous material ready to be made into paper is called pulp or wood cellulose.

Pulp is produced by two general methods: (1) mechanically by shredding or grinding the wood to free the fibers, or (2) chemically by cooking wood chips in an aqueous solution of pulping chemicals that dissolve the lignin binding material. Lignin is an amorphous polymeric substance related to cellulose that bonds the cellulose fibers together and forms the woody cell walls of plants. Generally wood contains 25 to 30 percent lignin on a dry basis.

In 1976, there were about 120 kraft pulp mills located in 28 states throughout the United States.[2-1] The majority of the mills are concentrated in the Southeast with the remainder concentrated in the Northwest and Northeast. A list of all kraft pulp mills operating in the United States as of 1976 is included as Appendix B.

In 1974, these mills produced 32,342,000 tons (2.93×10^{10} kg) of kraft pulp nearly all of which went into the production of paper, paperboard, and similar products. This represents approximately 70 percent of the pulp produced in the United States. Individual mill sizes range from 180 to 2,550 tons (1.6×10^5 to 2.3×10^6 kg) of pulp per day with the average being 770 tons (7×10^5 kg) per day.

The growth rate of the industry averaged 5-1/2 percent per year between 1956 and 1975. Growth has declined to 2-1/2 percent per year since 1975.[2-1]

The chemical pulping industry can be divided into four pulping categories: kraft, sulfite, neutral sulfite semichemical (NSSC), and soda.

The basic differences among these pulping processes are in the digestion of the wood chips. Kraft pulping uses a solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S) to accomplish the digestion. Sulfite pulping uses liquors containing sulfurous acid (H_2SO_3) and the bisulfite of calcium ($Ca(HSO_3)_2$), sodium ($NaHSO_3$), magnesium ($Mg(HSO_3)_2$), or ammonia (NH_4HSO_3). Neutral sulfite semichemical (NSSC) pulping uses a nearly neutral sulfite solution containing an alkaline agent such as sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), or NaOH. Soda pulping uses a solution of NaOH as the cooking liquor. The soda pulping process has declined to relative insignificance in recent years.

2.2 KRAFT PULP PRODUCTION PROCESS

The production of kraft pulp from wood is illustrated in Figure 2-1.[2-1] The kraft pulping process is the most widely used pulping process today. This is because of the efficient recovery and recycling of pulping chemicals, the strength of the pulp produced by the process, and the capability of using nearly all wood species to produce the pulp.

The pulping process is accomplished by chipping the wood into small pieces, transporting these wood chips to large pressure vessels (digesters, averaging about 4,000 ft^3 (110 m^3) in volume), and digesting the chips at elevated temperature and pressure in a cooking liquor consisting of a solution of NaOH and Na_2S known as white liquor. The NaOH in the white liquor is the principal pulping chemical. It permits the pulping of nearly all wood species. Na_2S speeds up the removal of lignin and provides a buffering action that allows digestion to take place at a lower $(OH)^-$ ion concentration. This results in less damaged and stronger pulps than those obtained in sulfite, NSSC, or soda pulping processes.[2-2]

Digesters are operated either in a batch or continuous mode (Figures 2-2 and 2-3.[2-3] The wood chips are generally digested at 340° to 360°F (170° to 180°C) and at pressures ranging from 100 to 135 pounds per square inch gauge (6.9×10^5 to 9.3×10^5 Pa). Depending upon the grade of wood chips, 45 to 55 percent of the wood reacts with the pulping chemicals to become soluble in the aqueous solution. This soluble portion of the wood consists of most of the lignin and hemi-celluloses and a small part of the cellulose. What remains of the wood, in the form of cellulose fibers, is the pulp.

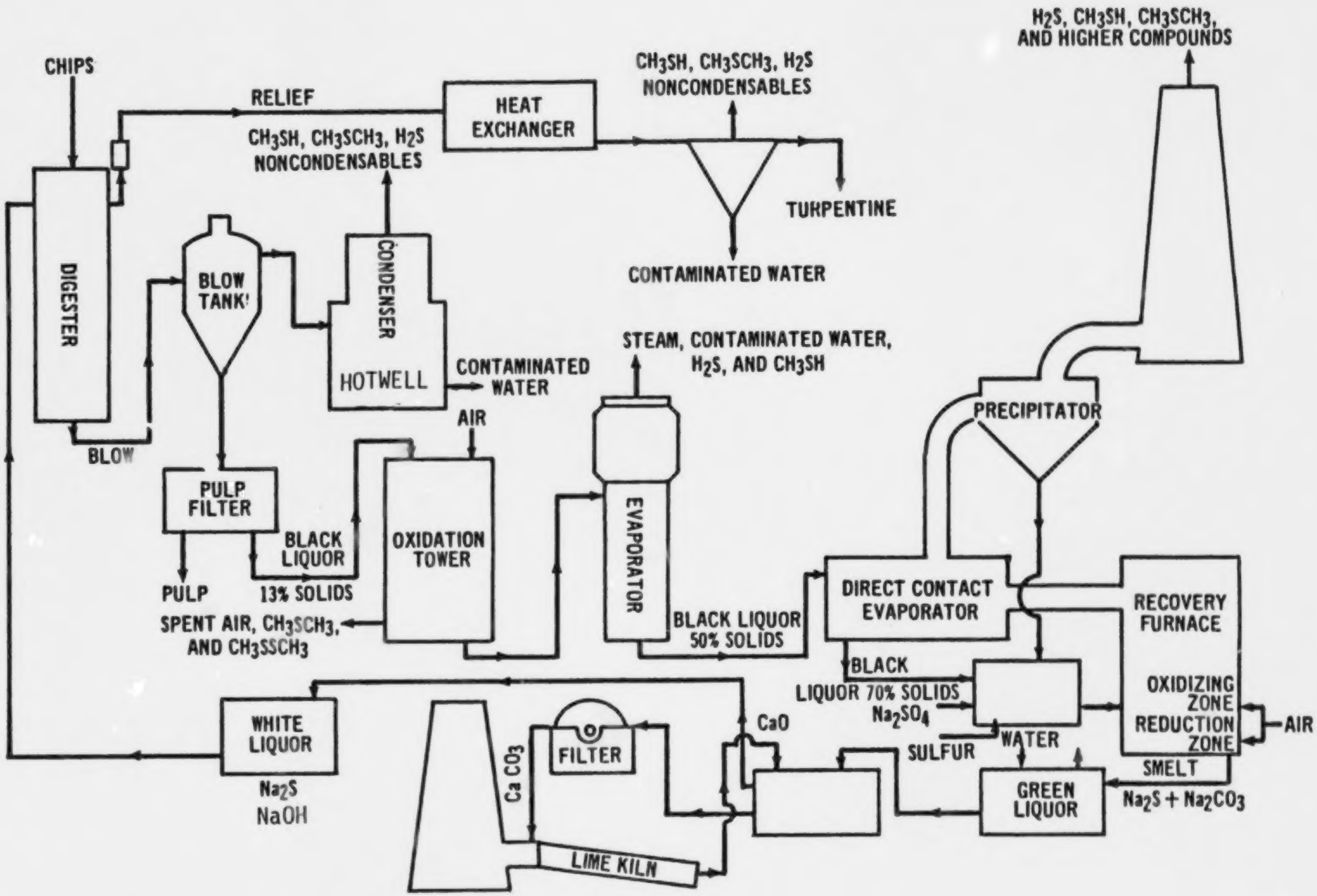
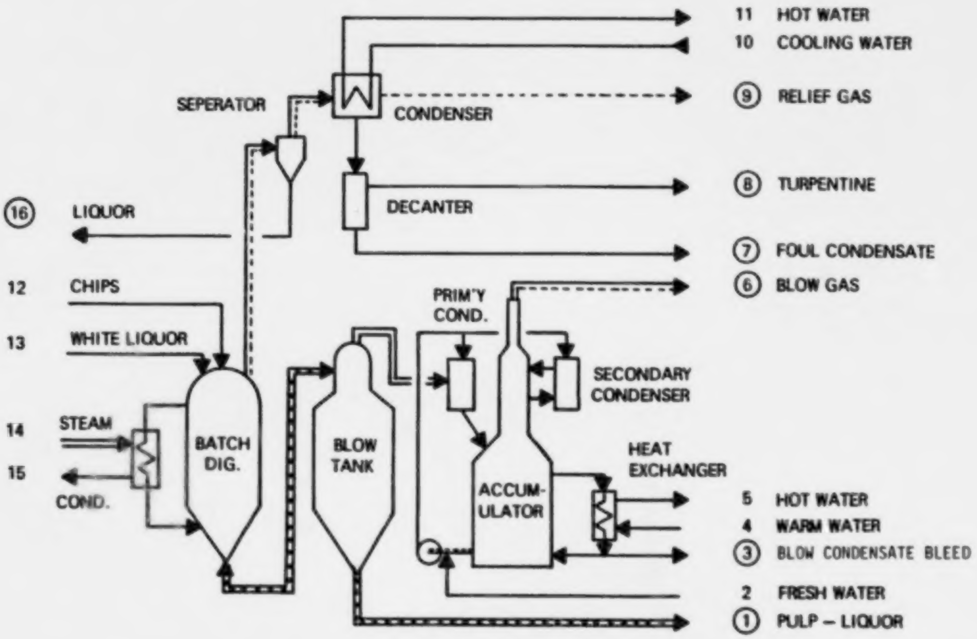

CHIPS
RELIEF
HEAT EXCHANGER
CH_3SH, CH_3SCH_3, H_2S NONCONDENSABLES
TURPENTINE
CONTAMINATED WATER
H_2S, CH_3SH, CH_3SCH_3, AND HIGHER COMPOUNDS
DIGESTER
BLOW TANK
CH_3SH, CH_3SCH_3, H_2S NONCONDENSABLES
CONDENSER
HOTWELL
CONTAMINATED WATER
BLOW
PULP FILTER
PULP
BLACK LIQUOR
13% SOLIDS
AIR
OXIDATION TOWER
SPENT AIR, CH_3SCH_3, AND CH_3SSCH_3
STEAM, CONTAMINATED WATER, H_2S, AND CH_3SH
EVAPORATOR
BLACK LIQUOR 50% SOLIDS
PRECIPITATOR
DIRECT CONTACT EVAPORATOR
BLACK LIQUOR 70% SOLIDS
Na_2SO_4
SULFUR
WATER
RECOVERY FURNACE
OXIDIZING ZONE
REDUCTION ZONE
AIR
SMELT
$Na_2S + Na_2CO_3$
GREEN LIQUOR
CaO
FILTER
$CaCO_3$
LIME KILN
WHITE LIQUOR
Na_2S
NaOH

Figure 2-1. Kraft pulping process.


11 HOT WATER
10 COOLING WATER
SEPERATOR
CONDENSER
⑨ RELIEF GAS
⑧ TURPENTINE
⑯ LIQUOR
DECANTER
⑦ FOUL CONDENSATE
12 CHIPS
PRIM'Y COND.
⑥ BLOW GAS
13 WHITE LIQUOR
SECONDARY CONDENSER
14 STEAM
BATCH DIG.
BLOW TANK
HEAT EXCHANGER
15
COND.
ACCUM-ULATOR
5 HOT WATER
4 WARM WATER
③ BLOW CONDENSATE BLEED
2 FRESH WATER
① PULP – LIQUOR

POINTS OF POSSIBLE ODOR RELEASE ARE ENCIRCLED BY ○

Figure 2-2. Batch digester flow sheet.

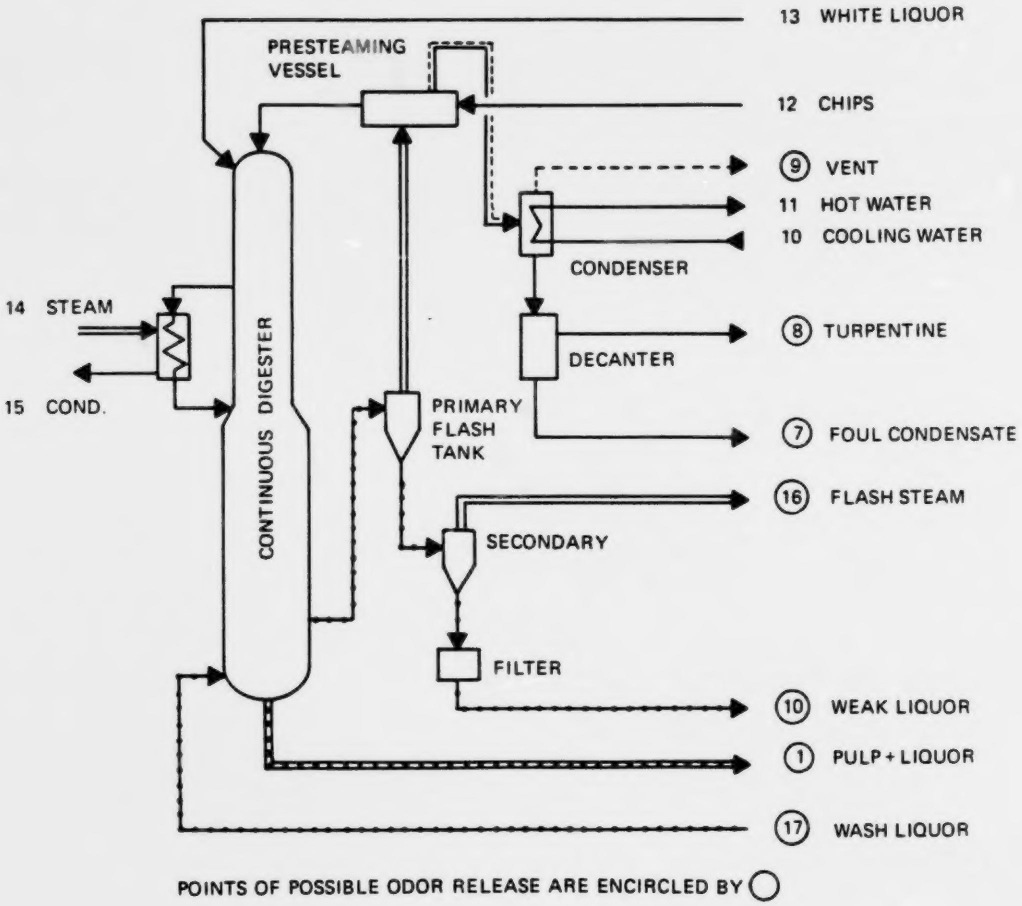

13 WHITE LIQUOR
PRESTEAMING VESSEL
12 CHIPS
9 VENT
11 HOT WATER
10 COOLING WATER
CONDENSER
14 STEAM
15 COND.
CONTINUOUS DIGESTER
8 TURPENTINE
DECANTER
PRIMARY FLASH TANK
7 FOUL CONDENSATE
16 FLASH STEAM
SECONDARY
FILTER
10 WEAK LIQUOR
1 PULP + LIQUOR
17 WASH LIQUOR
POINTS OF POSSIBLE ODOR RELEASE ARE ENCIRCLED BY ○

Figure 2-3. Continuous digester flow sheet.

To maintain proper cooking pressures within the digester, gases formed during digestion are vented. The composition and quantity of these digester gases differ between batch and continuous digesters. Variations also result from type of wood, temperature of cooking, cooking time, and sulfide concentration in the wood. In the cooking process, the sulfide ion reacts with the lignin in the wood to produce hydrogen sulfide (H_2S) and organic sulfide compounds (mostly methyl mercaptan (CH_3SH)), dimethyl sulfide ($(CH_3)_2S$), and dimethyl disulfide ($(CH_3)_2S_2$). The sulfide compounds are known as total reduced sulfur (TRS). The disagreeable odor from kraft pulp mills can be traced to these compounds and their low threshold odor levels (1 to 10 ppb).[2-2] Digester gas may also contain turpentine and traces of methanol (CH_3OH), ethanol (CH_3CH_2OH), and acetone (CH_3COCH_3).

At some mills the digester gases are first cooled to condense and recover turpentine prior to venting, especially if softwood is being pulped. These noncondensible relief-vent systems are used during the course of the cooking. At the end of the cooking cycle the pulp is discharged from the digester into an atmospheric tank usually referred to as a blow tank. For a batch process digester there may be a surge of gaseous emissions from this process resulting in blow gases which contain considerable amounts (26,000 ppm) of total reduced sulfur (TRS). Continuous digestors present fewer problems in that contaminated condensates and sulfur compounds flow at a regular rate while with batch digesters large amounts of steam and noncondensible gases are blown off when the contents of the digester are discharged to the blow tank at atmospheric pressure. Thus one can design controls for an average flow of gases with continuous digesters while one must provide control for peak gaseous emission flow with batch digesters. The steam in both the relief and blow gases is usually condensed to recover the heat while the noncondensible gases are vented or treated. Incineration in a lime kiln is the preferred method of treatment for these noncondensible gases.

Incineration of noncondensible gases produces sulfur dioxide (SO_2), which is retained in the lime instead of being emitted to the atmosphere. Other methods of treatment of noncondensible gases are scrubbing with NaOH, which removes only H_2S and CH_3SH, and scrubbing with chlorine solutions, which is of limited effectiveness. Often the chlorine scrubbing uses chlorination stage bleachery effluent from a bleaching plant which is at the same site as the kraft pulp mill.

The pulp slurry from the blow tank is generally screened through coarse screens known as knotters before it is washed. This process removes uncooked slivers and knots which are usually returned to the digesters for repulping.

Washing the pulp slurry is accomplished in a sequential countercurrent operation removing the spent white liquor and dissolved wood material (lignin, hemi-cellulose and a small amount of cellulose) from the pulp slurry. Generally three stages of vacuum drum washers are employed. The third stage is washed with hot, fresh (or recycled) water. The filtrates move countercurrently to the second stage of vacuum drum washers and then to the first stage, becoming what is termed weak black liquor (12 to 18 percent) solids. This weak black liquor is extracted from the first stage and is sent to multiple effect evaporators in the recovery plant. Mills containing continuous digesters sometimes do part of their washings in the digesters, thereby eliminating one or two stages of vacuum drum washers. The brown stock pulp resulting from these washings is further cleaned in screens and centrifugal cleaners before it is made into end products or bleached. No significant particulate matter emissions result from this cleaning process; however, gaseous emissions (mainly in the form of $(CH_3)_2S$ and $(CH_3)_2S_2$) have been found at the washer and knotter hoods, the filtrate tanks, and at the vacuum pumps.

The chemical recovery system is the heart of the kraft pulping process. The $NaOH$ and Na_2S must be recovered to permit viable economic operation of the kraft pulp mill. The weak black liquor (12 to 18 percent solids) recovered from the pulp at the washers is concentrated into a stronger black liquor (40 to 55 percent solids) by multiple effect evaporators. The concentration of the black liquor is necessary to permit combustion of the dissolved organic material in the recovery furnace. Liquid condensate and noncondensible vent gases give rise to emissions from this evaporation-concentration process. These evaporator gases contain sulfur and organic compounds which are boiled off from the weak black liquor or formed during the evaporation process. A major difference between evaporator gases and digester gases is that the evaporator gases are predominantly H_2S and CH_3SH while digester gases contain these gases as well as $(CH_3)_2S$ and $(CH_3)_2S_2$. Evaporator gas TRS emissions can be controlled through NaOH scrubbing while components of the digester gases ($(CH_3)_2S$ and $(CH_3)_2S_2$) cannot be controlled by this process. Incineration in a lime kiln is another possible control technique for evaporator gases. No significant particulate matter emissions result from the operation of multiple effect evaporators.

Multiple effect evaporators normally have three to seven stages. A diagram of a multiple effect long-tube vertical evaporator system is shown in Figure 2-4[2-2]. In this long-tube vertical shell-and-tube type evaporator the weak black liquor (12 to 18 percent solids) is fed to the tube side of the latter evaporation effects (or stages) while steam is supplied to the first effect's shell side. This steam-liquor countercurrent operation generally concentrates the black liquor solution to 40 to 55 percent solids. As shown in Figure 2-4, the weak black liquor moves through the tube side of the multiple effects from the last to the first. As the black liquor proceeds, it is heated by the condensation of the vapor that is driven off the boiling black liquor in the tube side of each preceding effect (on the left in Figure 2-4). The water vapor that is evaporated from the last effect (the far right effect in Figure 2-4) is generally condensed in one of two types of condensers with steam injectors: surface condensers and direct contact barometric condensers. The steam injectors are employed to remove noncondensibles. The multiple effect evaporators are normally operated at pressures of 20 to 40 psig (1.4×10^5 to 2.8×10^5 Pa) in the strong liquor outlet stage (left-hand side of Figure 2-4) and a vacuum of 25 to 28 in. of mercury (8.4×10^5 to 9.5×10^5 Pa) in the condenser stage (right-hand side of Figure 2-4).

Prior to final concentration in a direct contact evaporator or low odor furnace, the moderately strong black liquor (solids content: 40 to 55 percent), is commonly oxidized in oxygen or air to reduce TRS formation in the recovery furnace. The process oxidizes Na_2S to $Na_2S_2O_3$ or a higher oxidation state. The oxidation of Na_2S to $Na_2S_2O_3$ is given in the following equation:

$$2Na_2S + O_2 + H_2O \rightarrow Na_2S_2O_3 + 2NaOH$$

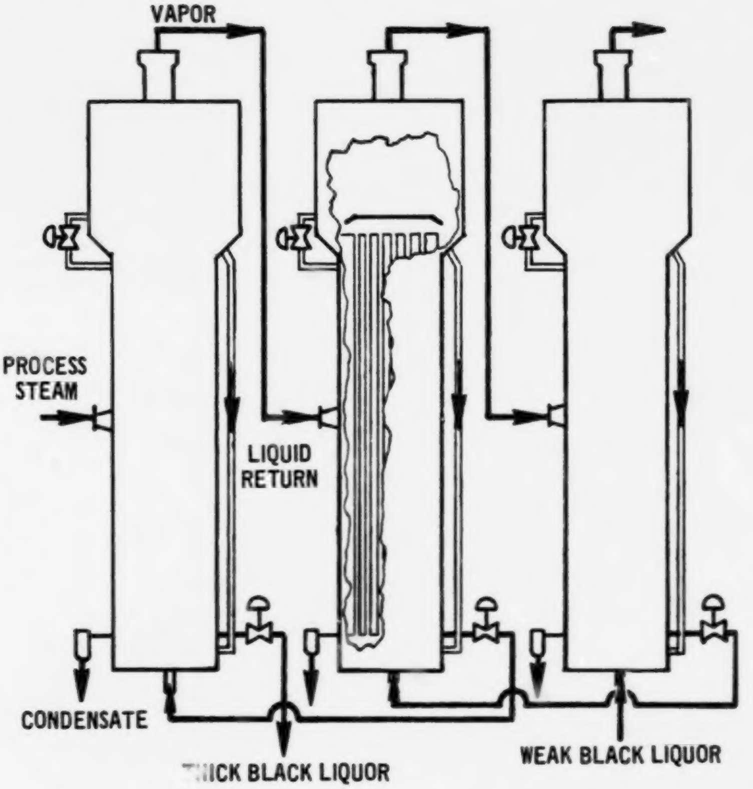

VAPOR
PROCESS STEAM
LIQUID RETURN
CONDENSATE
THICK BLACK LIQUOR
WEAK BLACK LIQUOR

Figure 2-4. Multiple effect long tube vertical evaporators (backward feed).

The $Na_2S_2O_3$ will not react with CO_2 and SO_2 in the recovery furnace gases to produce H_2S as Na_2S does. Thus, the black liquor oxidation results in lower H_2S emission rates. This oxidation can be performed on either the weak or moderately strong black liquor and is accomplished by employing air sparging reactors (with and without mechanical mixers), packed towers, and bubble tray columns in single and multiple stages to provide the necessary contact between the liquor and the air. The oxidation of the weak liquor may reduce emissions in the evaporation process, but there exists the possibility of reversion to the sulfide in later evaporation stages or in storage. No significant particulate matter emissions result from this black liquor oxidation.

The final concentration of the black liquor (from 40 to 55 percent solids to 60 to 70 percent solids) occurs in kraft recovery furnaces with direct contact evaporators (DCE) and kraft recovery furnaces without direct contact evaporators (low-odor furnaces). In the kraft recovery furnaces equipped with direct contact evaporators, the flue gas from the furnace is brought in contact with the moderately strong black liquor.

This final concentration process serves two purposes. Not only is it a final concentration process for the black liquor, but it also functions as a particulate emission control device which reduces particulate emitted by the recovery furnace by up to 50 percent.

Three types of direct contact evaporators are used to carry out this final concentration.

- When cyclone evaporators are used, the black liquor is sprayed into the hot gas stream from the recovery furnace, then the black liquor is removed by the cyclone. These cyclone evaporators are commonly believed to remove 40 to 50 percent of the particulate matter leaving the recovery furnace[2-2].
- In recovery furnaces employing cascade evaporators for the final black liquor concentration step, the black liquor is contacted with recovery furnace flue gas through the use of rotating wheels. The bottom portions of these rotating wheels move through a vat of black liquor that is carried into a moving beam of hot combustion gases. The cascade evaporator is believed to remove 40 to 50 percent of the particulate matter emitted from the recovery furnace.[2-2]

- The venturi recovery unit is the third type of direct contact evaporator used in the final concentration step of the black liquor. Venturi recovery units have been designed to remove at least 90 percent of particulate matter emitted from a source. When employed in the final concentration step for black liquor, the black liquor is mixed with a stream of recovery furnace flue gases at a venturi throat, and then is separated by a centrifugal separator.

The kraft recovery furnaces without direct contact evaporators (low-odor furnaces) employ two designs for final concentration of the black liquor. The first design uses additional stages of indirect evaporation of the black liquor plus added heat exchange in the furnace. This extended economizer section recovers the heat from the recovery furnace flue gas that is normally used in the direct contact evaporator to concentrate the black liquor. Thus the heat content of the flue gas is used, but the flue gas itself (containing CO_2 and SO_2) never contacts the black liquor in this final concentration step. The other system utilizes a flue gas-to-air heat exchanger and air direct contact evaporator. The flue gas is used to heat ambient air via a heat exchanger. This air is then used to concentrate the black liquor in a direct contact evaporator. What has occurred is that the recovery furnace flue gas with its CO_2 and SO_2 is replaced with air that contains minimal CO_2 and SO_2, thereby reducing malodorous sulfur gas emissions. After the air has been used in the direct contact evaporator to concentrate black liquor, it is then used as combustion air in the recovery furnace. While reducing the pollution problems associated with malodorous sulfur compounds, the recovery systems without flue gas direct contact evaporators have a particulate matter emission rate that is approximately double that arising from recovery systems with flue gas direct contact evaporators.

Once the solid content of the black liquor has been raised to 60 to 70 percent, the solution should support combustion, allowing recovery of chemicals from the black liquor. The chemicals should be recovered in the reduced state (that is, the sulfur should be present as sulfide and not sulfate). One of the useful byproducts of the combustion of the black liquor is the steam generated. The concentrated black liquor (60 to 70 percent solids) is usually mixed with any makeup chemicals (i.e., NA_2SO_4) before being sprayed into the recovery furnace for burning.

Recovery furnaces are one of the three major sources of particulate matter emissions in the kraft pulp mill industry. Figure 2-5 is a sketch of a recovery furnace showing the major operating zones. The black liquor is sprayed in small droplets over the cross section of the furnace. As the droplets fall through the drying section, they should be dried to a concentration where the heating value of the organic material in the black liquor will support reasonably stable combustion. The black liquor dry solids consisting primarily of Na_2S and Na_2CO_3 fall to the bottom of the furnace as a molten smelt and are removed to a smelt dissolving tank. The primary air flow is used to maintain a reducing atmosphere at the bottom of the furnace (to convert sulfur to sulfide and not to sulfate) and to maintain a proper smelt bed temperature. If the temperature of the smelt bed is too high, excessive amounts of sodium compounds will be volatilized from the bed, creating high particulate matter emission rates. If the smelt bed temperature is too low, insufficient sodium compounds will be volatilized into the reducing zone. This will result in higher sulfur compound emissions (TRS) as these compounds would normally react with the volatilized sodium compounds. The secondary air is used to create an oxidation zone where sulfur compounds can be ozidized to less odorous forms of sulfur such as SO_2.

The molten smelt in the recovery furnace is continuously discharged into a smelt dissolving tank (3,000 ft^3 to 5,000 ft^3 (85 m^3 to 140 m^3)) located beneath the recovery furnace. The molten smelt mixture, primarily consisting of Na_2S and Na_2CO_3, is mixed with water in the smelt tank to produce what is called green liquor. The smelt drops through steam shatter sprays into the dissolving tanks. The tanks are equipped with agitators to assist in dissolving the smelt. When the hot smelt contacts the water, copious amounts of steam are produced. Some particulate matter, consisting of both dissolved and undissolved NaOH, Na_2S, and Na_2CO_3, is entrained by the steam and carried out of the stack with the steam. Some reduced sulfur gases may also be formed by reactions in the tank and carried out with the steam. The smelt dissolving tank is one of the main particulate matter sources in the kraft pulp mill industry.

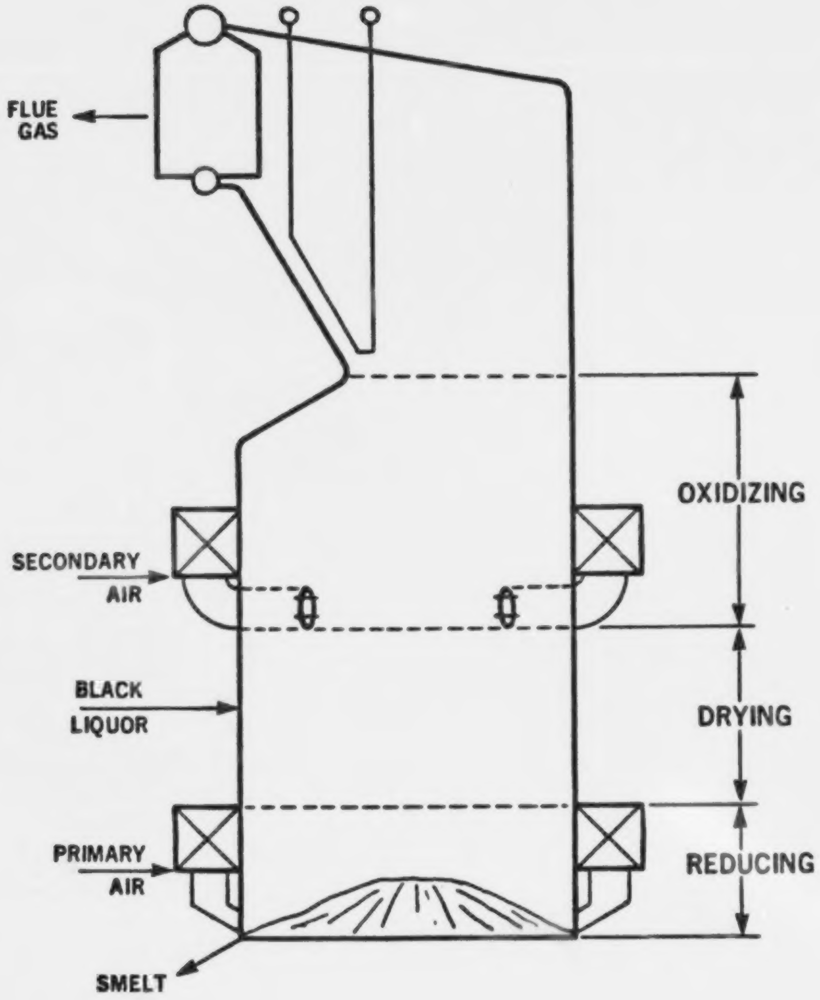

FLUE GAS
SECONDARY AIR
BLACK LIQUOR
PRIMARY AIR
SMELT
OXIDIZING
DRYING
REDUCING

Figure 2-5. Recovery unit furnace zones.[2-4]

The dissolved Na_2CO_3 in the green liquor is later causticized by adding quicklime (calcium oxide (CaO)) to it. The CaO is wetted (slaked) by the water in the green liquor to form calcium hydroxide ($Ca(OH)_2$) for the causticizing reaction. The resulting $CaCO_3$ precipitate is washed free of NaOH and calcined in a lime kiln. The following reactions in the causticizer form NaOH which is part of the white cooking liquor NaOH and Na_2S.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2NaOH + CaCO_3$$

As the lime moves down through the kiln, it agglomerates into small pellets and is finally calcined to calcium oxide in the high-temperature zone near the burner. Particulate matter is generated by the rolling and tumbling action of the material in the kiln. This material is carried along by the combustion gases. Some sodium compounds which vaporize at the high-temperature zone of the kiln and later condense also produce particulate matter emissions. Generally, the lime kiln particulate emissions are controlled by wet scrubbers.

Particulate Controls

The particulate control technologies used in the kraft pulp industry are presented in this section. Particulate control strategies are presented for emissions from:

- Recovery furnaces
- Lime kilns
- Smelt dissolving tank vents

Recovery Furnaces

Until recently, all recovery furnaces used a direct contact evaporator to concentrate the black liquor. However, it may also scrub particulate from the gas stream, removing up to 50 percent of the particulate in the gas stream.

As mentioned earlier, most direct contact evaporators are the cascade type in which the gases pass over a trough filled with black liquor. The liquor is scooped up by a rotating paddle wheel and cascades through the gas stream. Some kraft pulp mills use cyclones or venturis as the direct contact evaporator, with the black liquor again serving as the particulate scrubbing media. Occasionally, two venturis are used in series to increase particulate collection, obviating the need for additional controls. However, nearly all recovery furnaces now use electrostatic precipitators (ESP's) as their primary particulate control devices.[2-1] The design removal efficiency varies, however, ranging from 90 percent in the older installations to greater than 99 percent in the newer installations.

In some older installations, the existing units have been approved by installing scrubbers downstream from the ESP's. While in Sweden such practice is employed to increase heat recovery, the purpose in the United States is to improve particulate control removal efficiency. The scrubbers are used to reduce "snowing" (the emission of white particles resembling snowflakes) from inefficient ESP's. As the scrubbers are primarily low energy scrubbers, little additional removal would result of fine particulate which is emitted from a well designed and maintained ESP. It is reported that the principal cause of snowing is the electrode rapping done to dislodge collected material on the collection plates. The salt cake particles tend to be light and fluffy and upon rapping is dislodged and reentrained in the exhaust gases. Other causes of snowing are excessive electrical sparking and overloading during sootblowing or abnormal furnace operation.

Lime Kilns

Nearly all lime kilns are controlled with venturi scrubbers.[2-1] The typical venturi scrubber on a lime kiln in the kraft pulp industry operates with pressure drops ranging from 10 to 25 in. (2.5×10^3 to 6.2×10^3 Pa) of water. With such pressures, removal efficiencies of about 99 percent are possible. Impingement scrubbers have also been used in the industry with pressure drops of 5 to 6 in. (1.2×10^3 to 1.5×10^3 Pa) of water which result in removal efficiencies of only 90 percent.

While ESP's are found on lime kilns in Sweden, only a limited number are used in the United States. At one installation, an ESP has been retrofitted to control particulate emissions from three lime kilns with removal efficiency of about 99 percent.

Smelt Dissolving Tank Vents

Exhaust gases from smelt dissolving tank vents are ducted through demister pads, packed towers, or venturi scrubbers for particulate control.

Demister pads are basically fine wire mesh screens about 1 ft (0.3 m) thick which act as a low energy scrubber. Droplets condense on the mesh and are backflushed with water sprays into the smelt dissolving tank. Low pressure drop venturis (6 to 8 in. of water (1.5×10^3 to 2.0×10^3 Pa)) and packed towers are also used in the industry with particulate removal efficiency of up to 95 percent.

Occasionally, smelt dissolving tank gases are combined with recovery furnace gases and ducted to a common ESP.[2-1]

References for Section 2

2-1. "Standards Support and Environmental Impact Statement," Volume 1: Proposed Standards of Performance for Kraft Pulp Mills, EPA-450-2-76-14-a, U. S. Environmental Protection Agency, 1976.

2-2. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry, Cooperative Study of EPA-450/1-73-002 and NCASI, Atmospheric Quality Improvement Technical Bulletin No. 69.

2-3. Environmental Pollution Control: Pulp and Paper Industry, Part I Air, EPA-625/7-76-001, U. S. Environmental Protection Agency, 1976.

2-4. Air Pollution Emission and Control Technology: Wood Pulping Industry. EPS-3-AP-77-6, Environmental Protection Service of Canada, 1979.

SECTION 3

KRAFT PULP INDUSTRY EMISSION FACTORS

Cumulative size specific emission factors have been developed for the kraft pulp industry based upon Southwest Research Institute (SoRI) two-cyclone train and cascade impactor test results. Emission factors are presented for uncontrolled and controlled emissions from

- Recovery furnaces
- Lime kilns
- Smelt dissolving tank vents

As described in Section 1, an extensive literature review was conducted to locate inhalable particulate data. Sources of data that reported the results of measurements and observations of the author were considered as primary sources. Secondary sources were those where the author reported emission data performed by a different organization. Primary sources are the most highly desirable sources of data for calculating inhalable particulate emission factors. However, when attempts failed to obtain the primary sources on which key secondary sources were based, it became necessary to utilize those secondary sources in the development of inhalable particulate emission factors for the kraft pulp industry.

All data sources thus collected were ranked using the A through D grading system based on data quality and reliability according to the criteria from AP-42,[3-1] described in Section 2.

3.1 EMISSION FACTORS BASED ON A-RATED DATA

As described earlier, preference was given to emission factors that could be calculated directly from the data available. Table 3-1 presents a summary of the A-rated emission data. Data were available for three emission sources:

- A recovery furnace with a direct contact evaporator, hereafter identified as "recovery furnace (DCE)"

TABLE 3-1. SUMMARY OF A-RATED EMISSION DATA

Emission point	Source	Control device	Type of emission data	Date	Reference
Recovery furnace (DCE)	Longview Fiber Company Longview, WA	ESP	Controlled and uncontrolled	September 1981	3-2
Recovery furnace (non-DCE)	St. Regis Paper Company Tacoma, WA	ESP	Controlled and uncontrolled	September 1981	3-2
Lime kiln	Longview Fiber Company Longview, WA	Venturi scrubber	Controlled and uncontrolled	September-October 1981	3-2

- A recovery furnace without a direct contact evaporator (i.e., a low-odor furnace), hereafter identified as "recovery furnace (non-DCE)
- A lime kiln

Similar data for emissions from a smelt dissolving tank vent were judged to be unacceptable for calculation of emission factors for reasons described under "Other Emission Data."

Recovery Furnace (DCE), Longview Fibre

Data were obtained from a series of particulate mass and particle size tests conducted on the no. 19 recovery furnace at the Longview Fibre Company. The purpose of the tests was to quantify and characterize particulate matter particle size emission factors at 15 and 2.5 µm diameters for uncontrolled and controlled emissions. The no. 19 recovery furnace was manufactured by Combustion Engineering and burns 240 to 280 gal/min (1.5×10^{-2} to 1.8×10^{-2} m^3/sec) of black liquor with a solids content of approximately 65 percent. Makeup salt is seldom added during the process. Particulate matter in the furnace exhaust gases is removed by a Research-Cottrell ESP. It has two parallel chambers, each having eight electrical fields. The results of the emission tests on the no. 19 recovery furnace are summarized in Table 3-2 and the cumulative emission factors are shown graphically in Figures 3-1 and 3-2.

Recovery Furnace (Non-DCE), St. Regis Paper Co.

A series of particulate mass and particle size tests similar to those at Longview Fibre were conducted on the non-DCE recovery furnace at St. Regis Paper Co. The purpose was to quantify and characterize particulate matter particle size emission factors at 15 and 2.5 µm diameter for uncontrolled and controlled emissions. The no. 4 recovery furnace, on which the tests were made, was manufactured by Combustion Engineering. The furnace burns 200 to 250 gal/min (1.3×10^{-2} to 1.6×10^{-2} m^3/sec) of black liquor with a solids content of approximately 65 percent. The amount of makeup salt in the process varies with different white liquor cooking batches. Particulate matter is removed from the flue gases by a Wheelabrator/Lurgi ESP with two parallel chambers with four electrical fields per chamber. The results of the emission tests on the no. 4 furnace are summarized in Table 3-3 and the cumulative emission factors shown graphically in Figures 3-3 and 3-4.

TABLE 3-2. SIZE DISTRIBUTION AND MASS EMISSION FACTORS FOR UNCONTROLLED AND ESP CONTROLLED EMISSIONS FROM A RECOVERY FURNACE (DCE) AT LONGVIEW, WASHINGTON[a]

Particle size (μm)	Size distribution, mass		Emission factors	
	Uncontrolled (percent)	Controlled (percent)	Uncontrolled (lb/ton)[b]	Controlled (lb/ton)[b]
Total	100.00	100.00	97.03	0.736
>15	4.02	22.30	3.95	0.169
2.5 to 15	18.37	31.77	18.38	0.238
<2.5	77.61	45.93	74.70	0.330

[a] Data represent the average of three tests.

[b] Tons of air dried pulp. To convert to kilograms per megagram, multiply by 0.5.

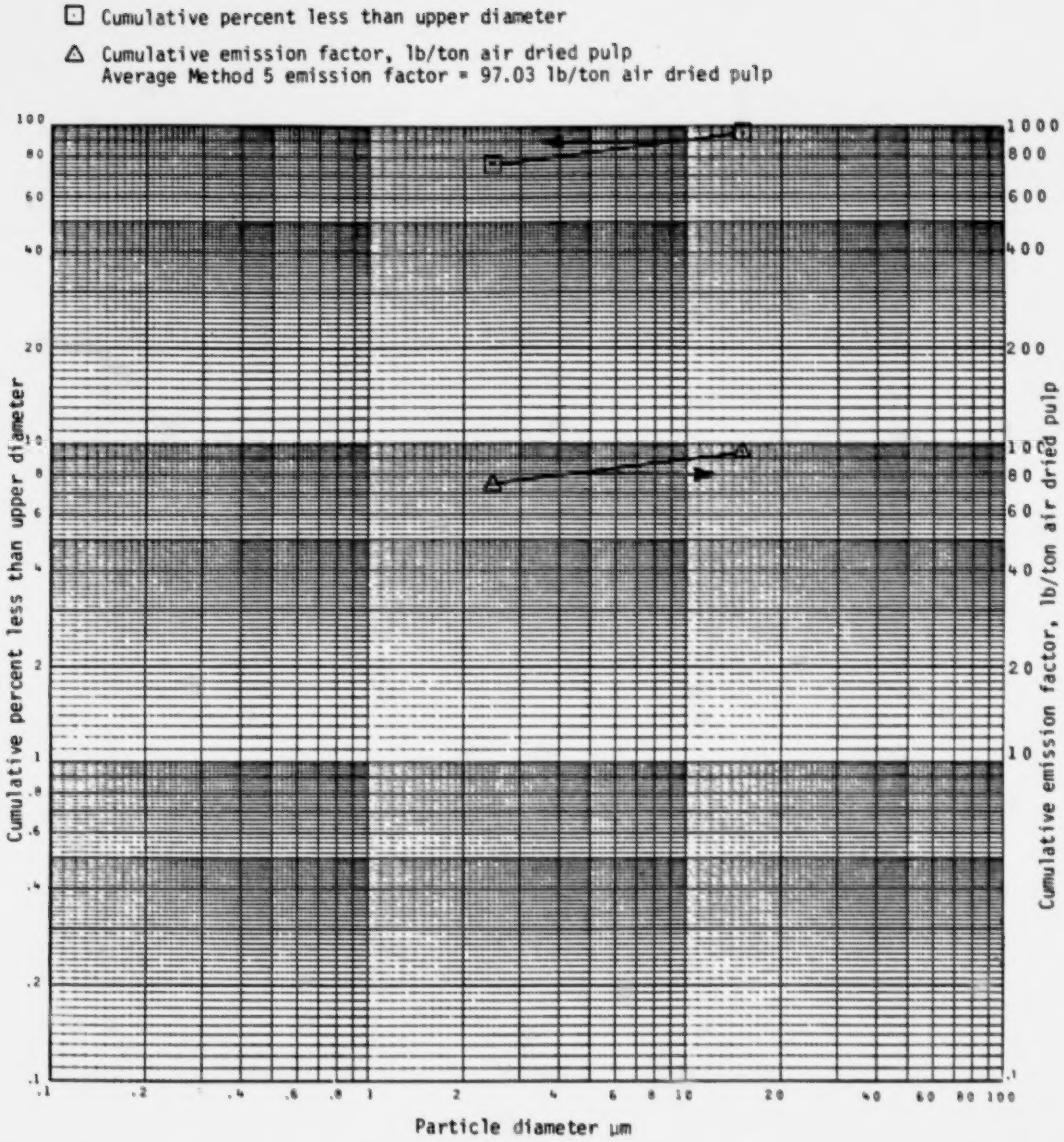


Figure 3-1. Cumulative size distribution and emission factors for uncontrolled emissions from a recovery furnace (DCE) at Longview, Washington.[3-2]

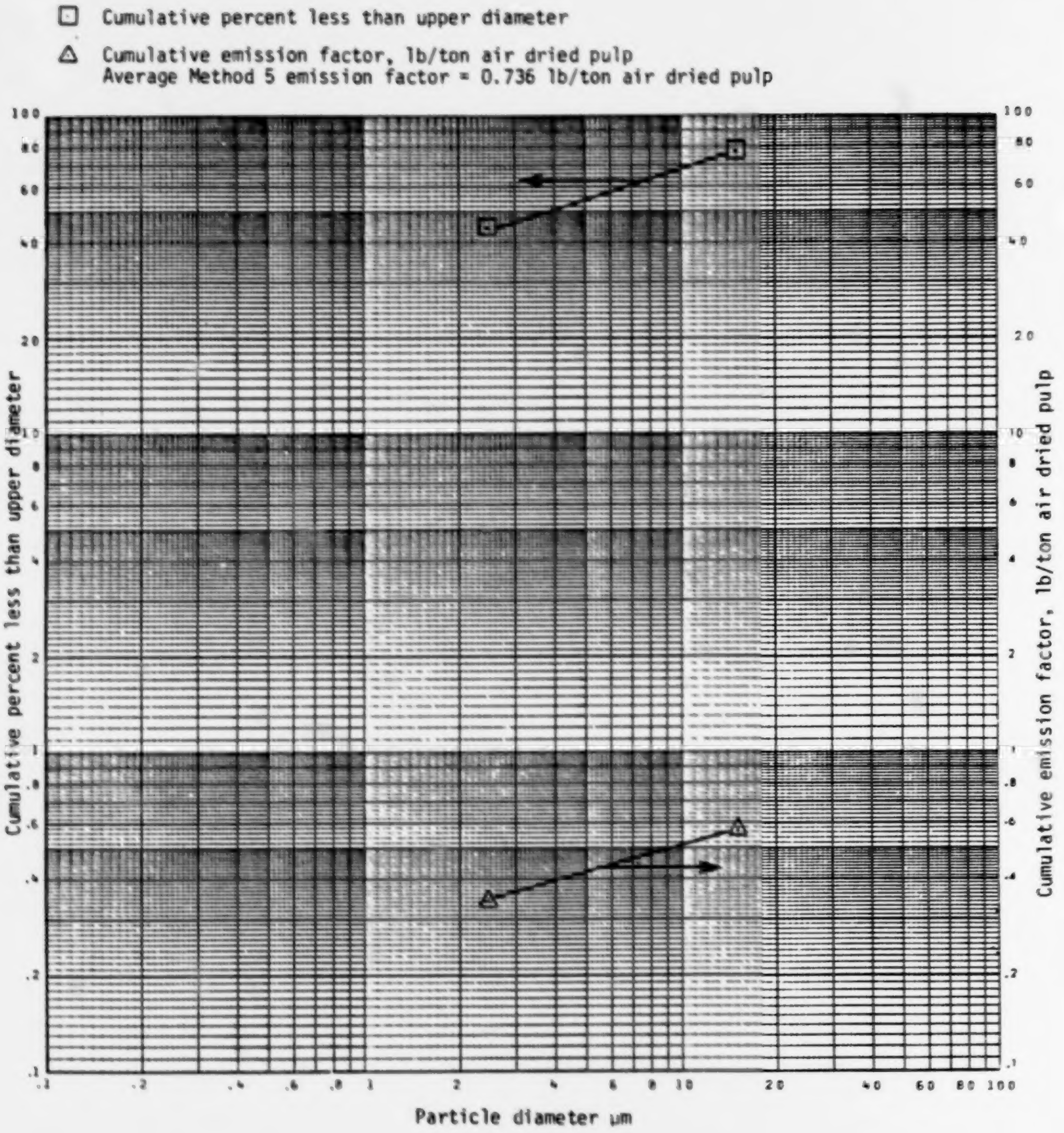


Figure 3-2. Cumulative size distribution and emission factors for ESP controlled emissions from a recovery furnace (DCE) at Longview, Washington.[3-2]

TABLE 3-3. SIZE DISTRIBUTION AND MASS EMISSION FACTORS FOR UNCONTROLLED AND ESP CONTROLLED EMISSIONS FROM A RECOVERY FURNACE (NON-DCE) AT TACOMA, WASHINGTON[a]

	Size distribution mass		Emission factors	
Particle size (µm)	Uncontrolled (percent)	Controlled (percent)	Uncontrolled (lb/ton)[b]	Controlled (lb/ton)[b]
Total	100	100	99.07	1.66
>15	19.22	17.95	18.80	0.36
2.5 to 15	9.97	11.85	9.90	0.19
<2.5	70.82	70.20	70.39	1.12

[a] Data represents the average of two tests.

[b] Tons of air dried pulp. To convert to kilograms per megagram, multiply by 0.5.

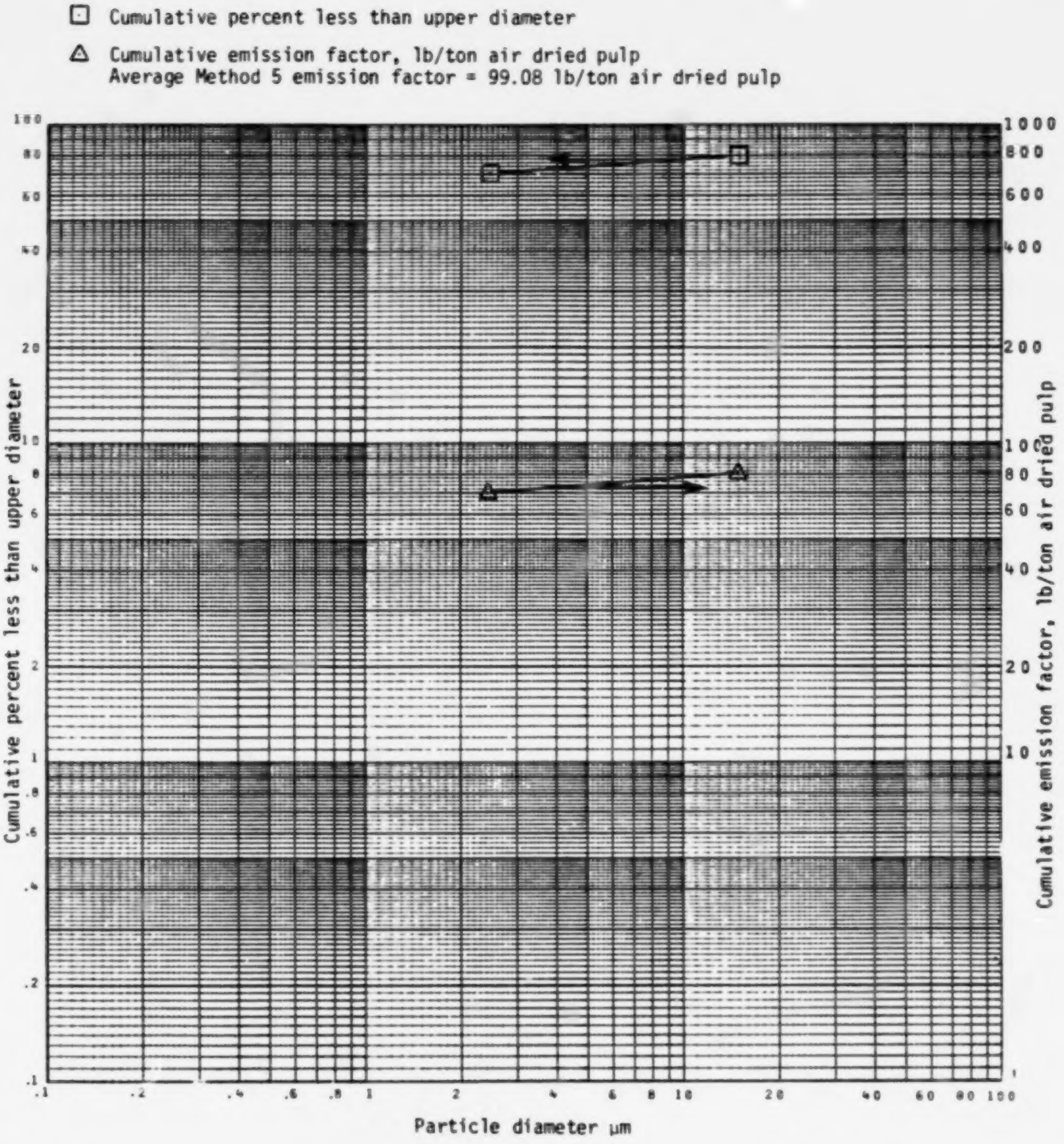


Figure 3-3. Cumulative size distribution and emission factors for uncontrolled emissions from a recovery furnace (non-DCE) at Tacoma, Washington.[3-2]

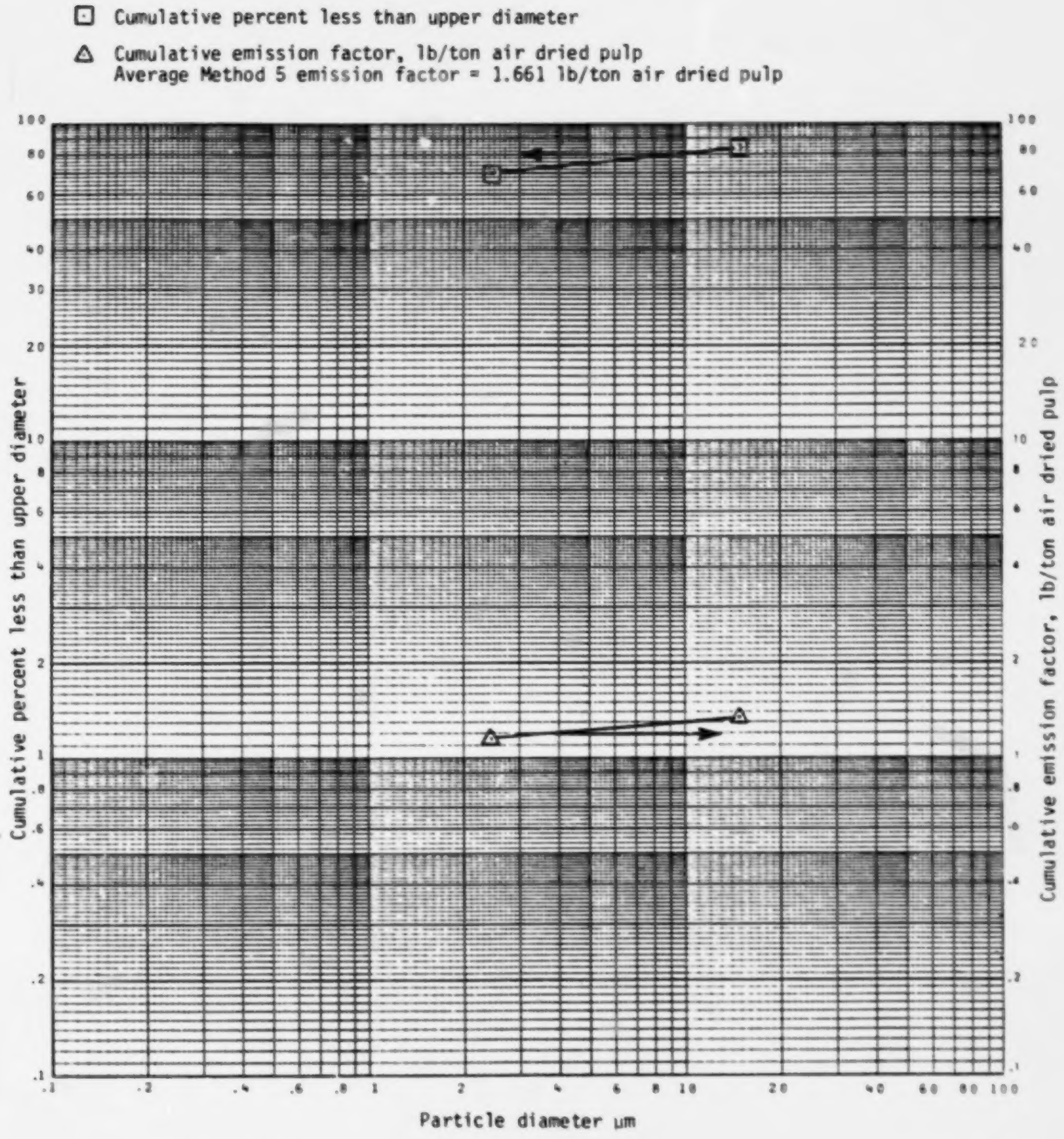


Figure 3-4. Cumulative size distribution and emission factors for ESP controlled emissions from a recovery furnace (non-DCE) at Tacoma, Washington.[3-2]

Lime Kiln, Longview Fibre Co.

The data for the lime kiln presented here were obtained from a series of particulate mass and particle size tests conducted on the no. 2 lime kiln at Longview Fibre Company. The purpose of the tests was to quantify and characterize particulate matter particle size emission factors for uncontrolled and controlled emissions. Uncontrolled emissions were measured using SoRI two cyclone train with backup filter. Controlled emissions were measured using an Anderson Mark III impactor with a 15-μm precutter. The no. 2 lime kiln was built by Traylor and produces 120 tons/day (1.1×10^5 kg/day) of lime. It is equipped with a Ducon Venturi scrubber to control particulate emissions. The results of the emission tests on the lime kiln are summarized in Tables 3-4 and 3-5 and presented graphically in Figures 3-5 and 3-6.

3.2 EMISSION FACTORS BASED UPON B-RATED DATA

Table 3-6 presents a summary of the B-rated emission data. Data were rated B because the cumulative size specific emission factors must be obtained by multiplying the mass emission factor presented in AP-42[3-1] by the appropriate size distribution factor. Data were not available with which to calculate size specific emission factors directly. The majority of data obtained through the extensive literature search fall into this category as shown in Table 3-6 and are from a single reference, Technical Bulletin No. 94 published by NCASI[3-3]. The sources of the data were not identified in the bulletin and, therefore, data were identified in this report by the reference number assigned to them in Technical Bulletin No. 94.[3-3] For purposes of comparison, data were analyzed for 0.625, 1.00, 1.25, 2.5, 6, 10 and 15 μm aerodynamic diameters.

Recovery Furnace (DCE) -- Uncontrolled Emissions

Bosch, et al.[3-3,3-6,3-8] and Pilat et al.[3-8] measured the size distribution of particulates emitted from a DCE recovery furnace for the purpose of evaluating a new type of cascade impactor. Cumulative weight percentages were arithmetically averaged to obtain the size distribution shown in Figure 3-7.

Larssen, et al.[3-3,3-9] conducted tests on the DCE recovery furnace sampled previously by Bosch et al. Using a University of Washington Mark I cascade impactor. The results obtained are shown in Figure 3-8.

TABLE 3-4. SIZE DISTRIBUTION AND MASS EMISSION FACTORS FOR UNCONTROLLED EMISSIONS FROM A LIME KILN AT LONGVIEW, WASHINGTON[a]

Particle size (μm)	Size distribution mass uncontrolled (percent)	Emission factors uncontrolled (lb/ton)[b]
Total	100.00	82.04
>15	68.37	55.85
2.5 to 15	18.87	15.71
<2.5	12.77	10.47

[a] Data represent the average of two tests.

[b] Tons of air dried pulp. To convert to kilograms per megagram, multiply by 0.5.

TABLE 3-5. CUMULATIVE SIZE DISTRIBUTION AND MASS EMISSION FACTORS FOR SCRUBBER CONTROLLED EMISSIONS FROM A LIME KILN AT LONGVIEW, WASHINGTON[a]

Particle size d_{50} (µm)	Cumulative mass (percent)	Cumulative emission factor controlled (lb/ton)[b]
11.6	71.59	0.44
10.5	71.07	0.44
6.7	70.87	0.44
4.4	69.50	0.43
2.4	68.78	0.43
1.3	66.86	0.41
0.68	59.77	0.37
0.37	43.54	0.27

[a] Data represent the average of two tests.

[b] Tons of air dried pulp. To convert to kilograms per megagram, multiply by 0.5.

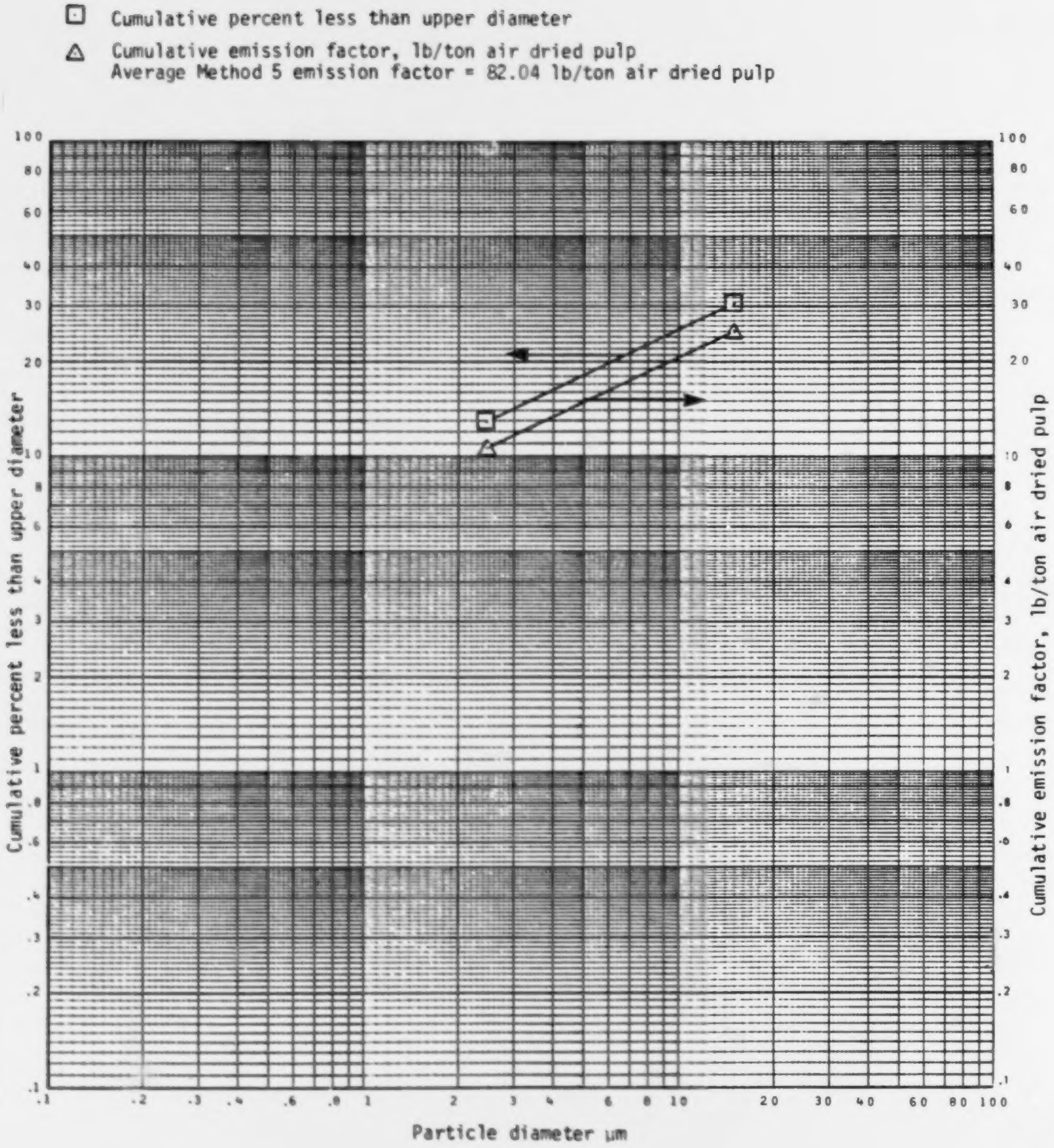


Figure 3-5. Cumulative size distribution and emission factors for uncontrolled emissions from a lime kiln at Longview, Washington.[3-2]

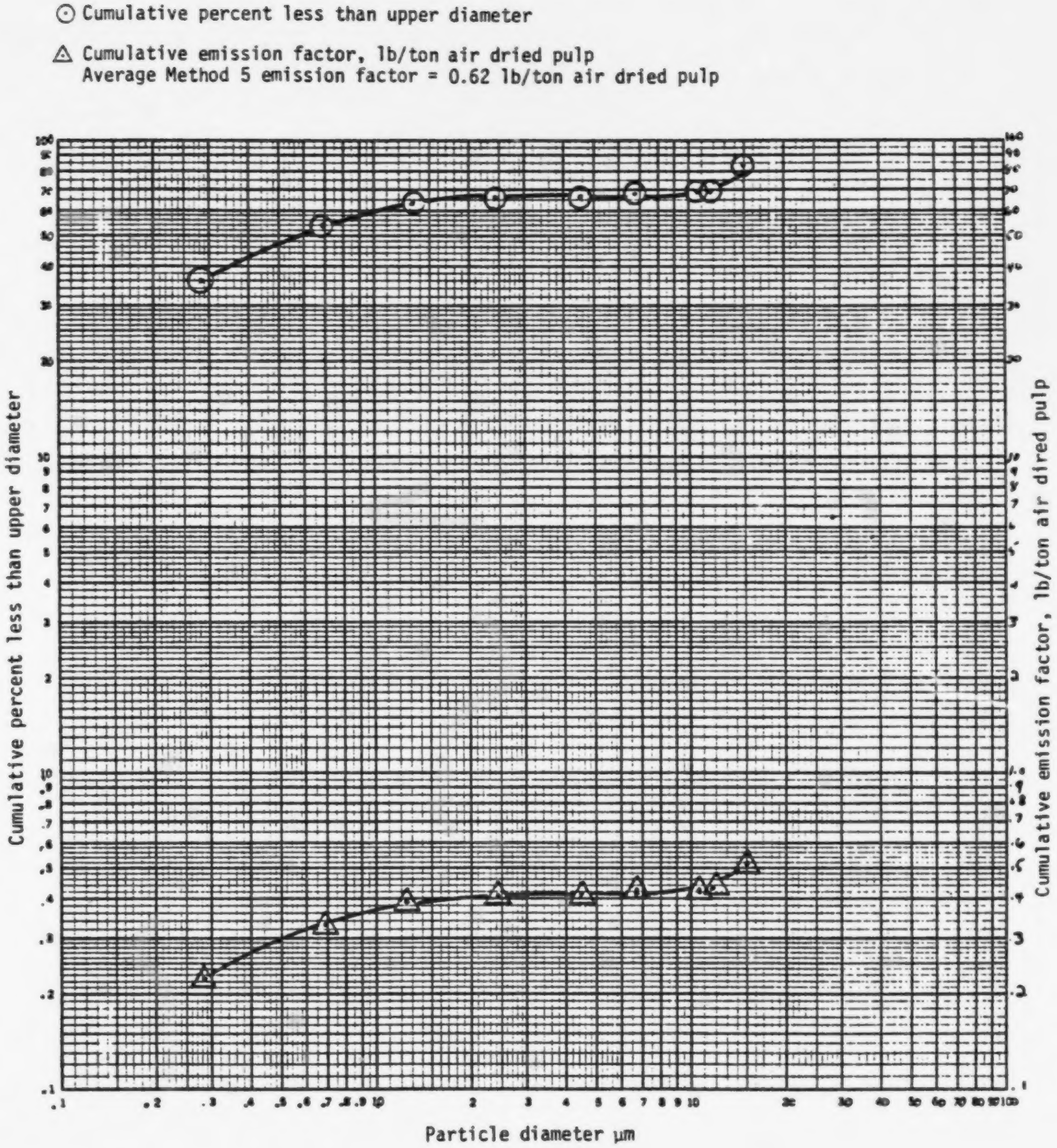


Figure 3-6. Cumulative size distribution and emission factors for venturi scrubber controlled emissions from a lime kiln at Longview, Washington.3-2

TABLE 3-6. SUMMARY OF B-RATED EMISSION DATA

Emission point	Source and location	Control device	Type of emission data	Date	Reference
Recovery furnace (DCE)	St. Regis Paper Co. Tacoma, Washington "49"	--	Uncontrolled	June-July 1969	3-3,3-6,3-8
Recovery furnace (DCE)	Not specified "53"	ESP	Uncontrolled	Not specified	3-3,3-9
Recovery furnace (DCE)	Not specified "54"	ESP	Uncontrolled and controlled	Not specified	3-3
Recovery furnace (DCE)	Not specified	ESP	Controlled	Not specified	3-4
Recovery boiler (non-DCE)	Not specified "47"	--	Uncontrolled	Not specified	3-3,3-5
Recovery furnace (non-DCE)	Not specified "56"	ESP	Controlled	Not specified	3-3
Recovery furnace (non-DCE)	Not specified "57"	ESP	Controlled	Not specified	3-3
Recovery furnace (non-DCE)	Not specified "58"	ESP	Controlled	Not specified	3-3
Recovery furnace (non-DCE)	Not specified	ESP	Controlled	Not specified	3-3
Lime kiln	Not specified "61"	--	Uncontrolled	Not specified	3-3
Lime kiln	Not specified "62"	Venturi scrubber	Controlled	Not specified	3-3
Lime kiln	Not specified "63"	ESP	Controlled	Not specified	3-3
Smelt dissolving tank vent	Not specified "64"	Packed tower	Uncontrolled	Not specified	3-3
Smelt dissolving tank vent	Not specified "65"	Packed tower	Controlled	Not specified	3-3
Smelt dissolving tank vent	Not specified "66"	Venturi scrubber	Controlled	Not specified	3-3

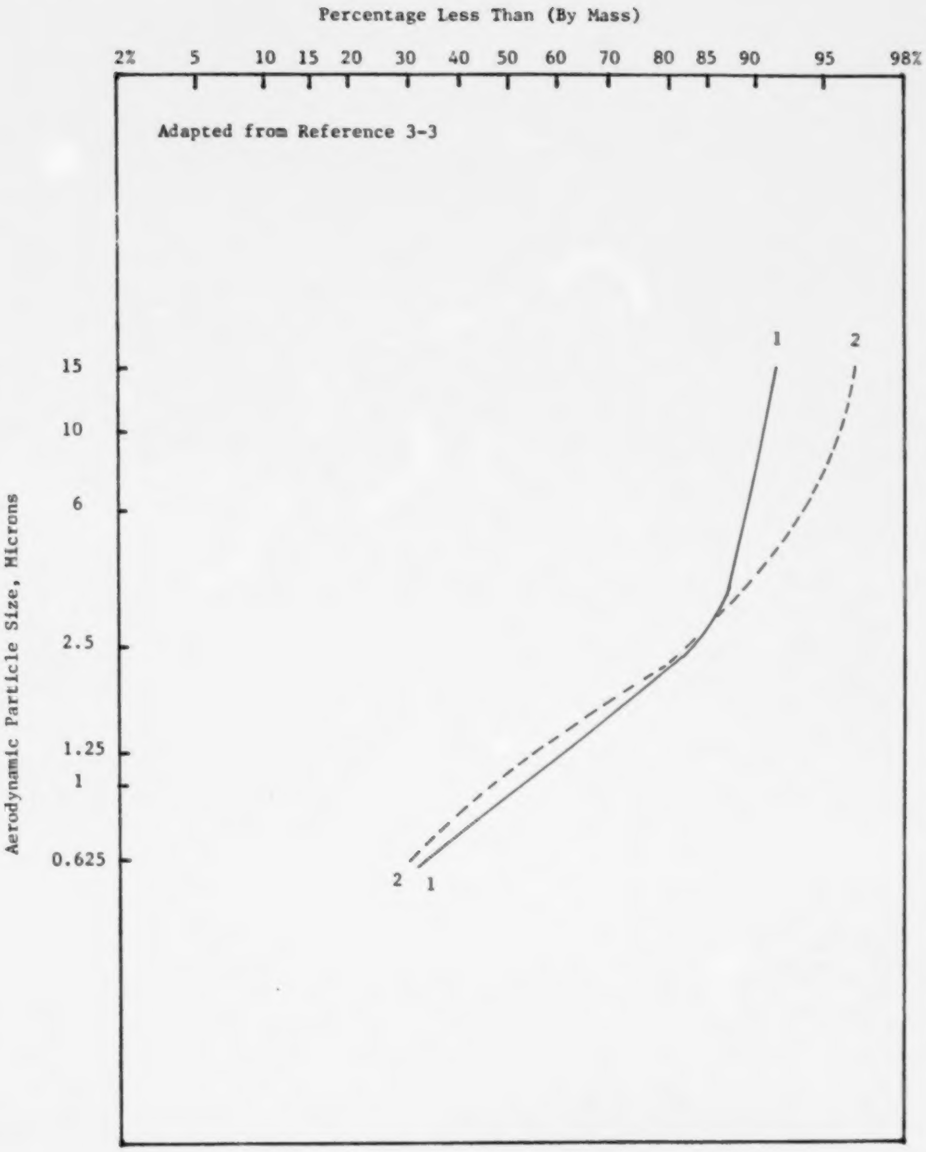


Figure 3-7. Cumulative size distribution for uncontrolled emissions from a recovery furnace (DCE) at site "49".

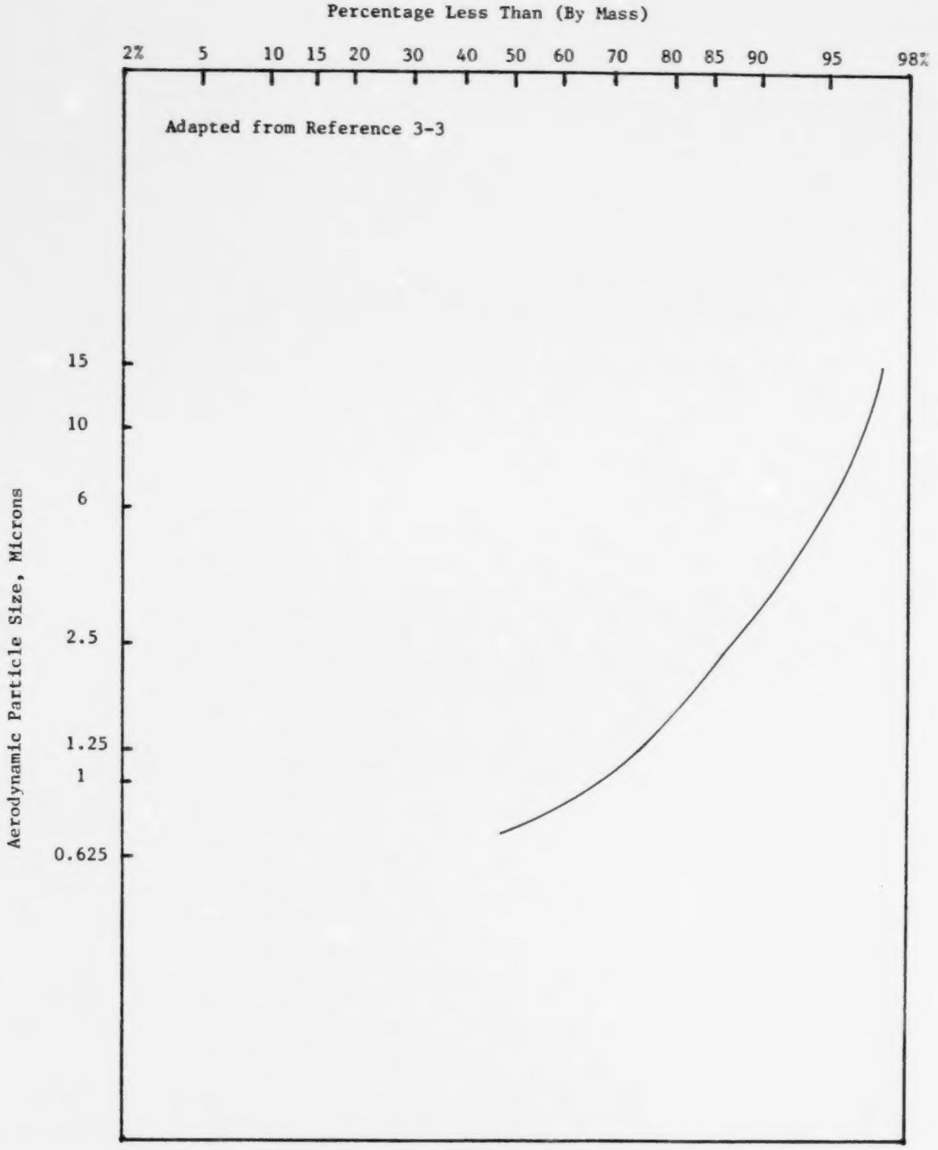


Figure 3-8. Cumulative size distribution for uncontrolled emissions from a recovery furnace (DCE) at site "53".

Kutyna[3-3] measured the particle size distribution in the uncontrolled flue gas from a DCE recovery boiler using a Brink cascade impactor and in-line cyclone. The results are presented in Figure 3-9.

The results of these measurements on uncontrolled emissions are summarized in Table 3-7 for the cut points of concern. The values were obtained directly from the Figures presented in Technical Bulletin No. 94.[3-3]

Recovery Furnace (DCE) -- Controlled Emissions

Particle size distribution for controlled emissions from DCE recovery furnaces corresponded in both cases to furnaces equipped with ESP's. Kutyna[3-3] sampled a recovery furnace equipped with a four-field ESP to obtain the results presented in Figure 3-10. Additional data, shown in Figure 3-11, were obtained from NCASI.[3-4] Both sets of data are summarized in Table 3-8.

Recovery Furnace (Non-DCE) -- Uncontrolled Emissions

Only one set of data was found for uncontrolled emissions from a non-DCE recovery furnace. Paul[3-3,3-5] reported results for a series of four sampling tests as shown in Figure 3-12. The important data points are tabulated in Table 3-9.

Recovery Furnace (Non-DCE) -- Controlled Emissions

A significant amount of data exists on emissions from non-DCE recovery furnaces equipped with ESP's.

Figure 3-13[3-3] presents data for a non-DCE recovery furnace equipped with an ESP with a design efficiency of 99.8 percent. Seven particle sizing tests were conducted over a 10-day period on another non-DCE recovery furnace equipped with an ESP.[3-3] The Mark III cascade impactor was used to obtain the data shown in Figure 3-14. The same furnace was sampled subsequently by NCASI using the Mark III cascade impactor with the results shown in Figure 3-15.[3-3] As reported, the change in distribution to greater fine particulate was due to the application of increased insulation to minimize heat losses prior to flue gases exiting the stack.

Four Mark III cascade impactor tests were made at a non-DCE recovery furnace equipped with a two-chamber, four-field ESP.[3-13] The results are shown in Figure 3-16. It has been reported that the first three tests were under normal plant operating conditions but the fourth test occurred during "slightly abnormal furnace operation and power regulation difficulties with the last field of the ESP."

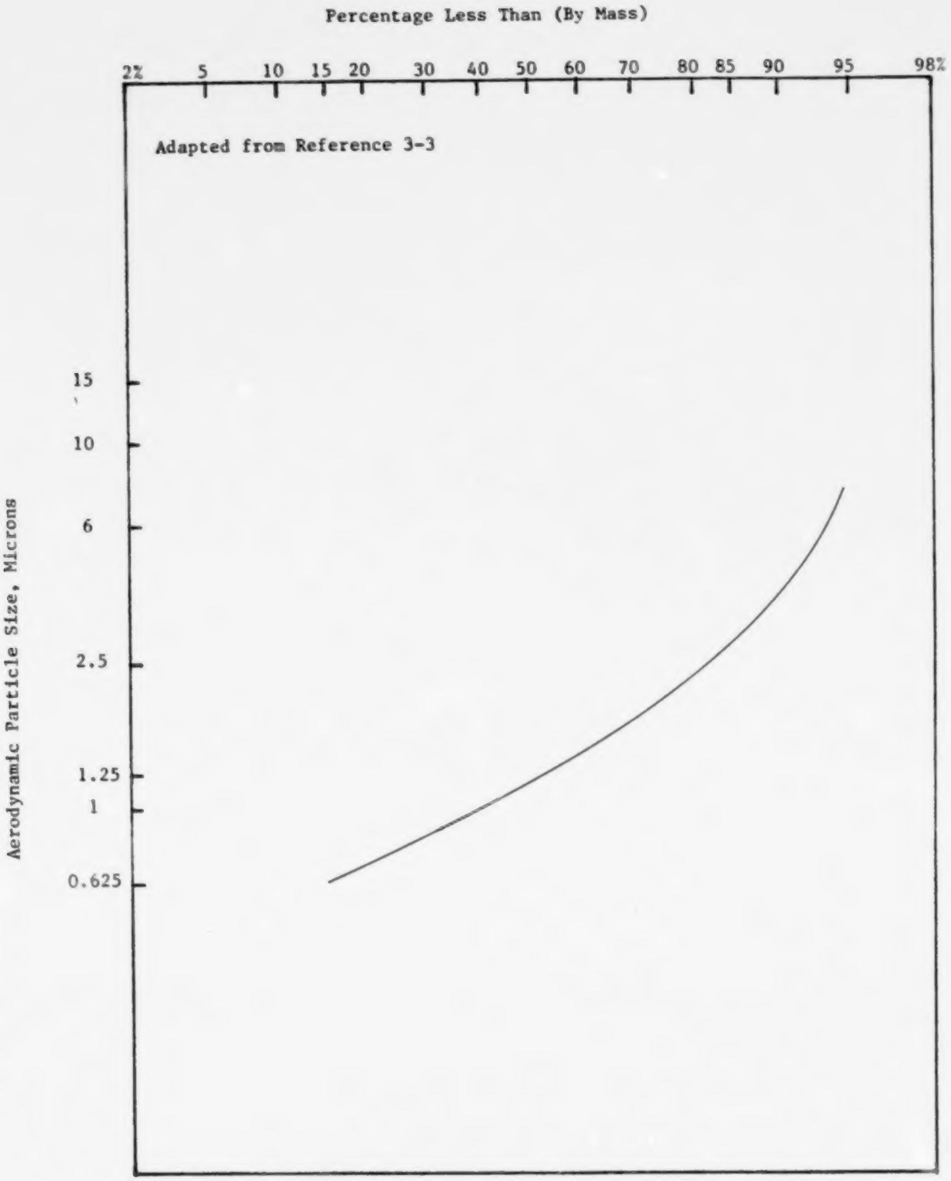


Figure 3-9. Cumulative size distribution for uncontrolled emissions from a recovery furnace (DCE) at site "54".

TABLE 3-7. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A RECOVERY FURNACE (DCE)

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "49"	3-3,3-6,3-8	100.0	93.0	91.0	89.5	83.0	63.0	53.0	33.5
Unspecified "53"	3-3,3-5	100.0	97.0	96.0	94.0	85.0	56.5	48.0	31.5
Unspecified "54"	3-3	100.0	--	--	93.0	82.5	50.0	35.0	14.5
Mean		100.0	95.0	93.5	92.2	83.5	56.5	45.3	26.5

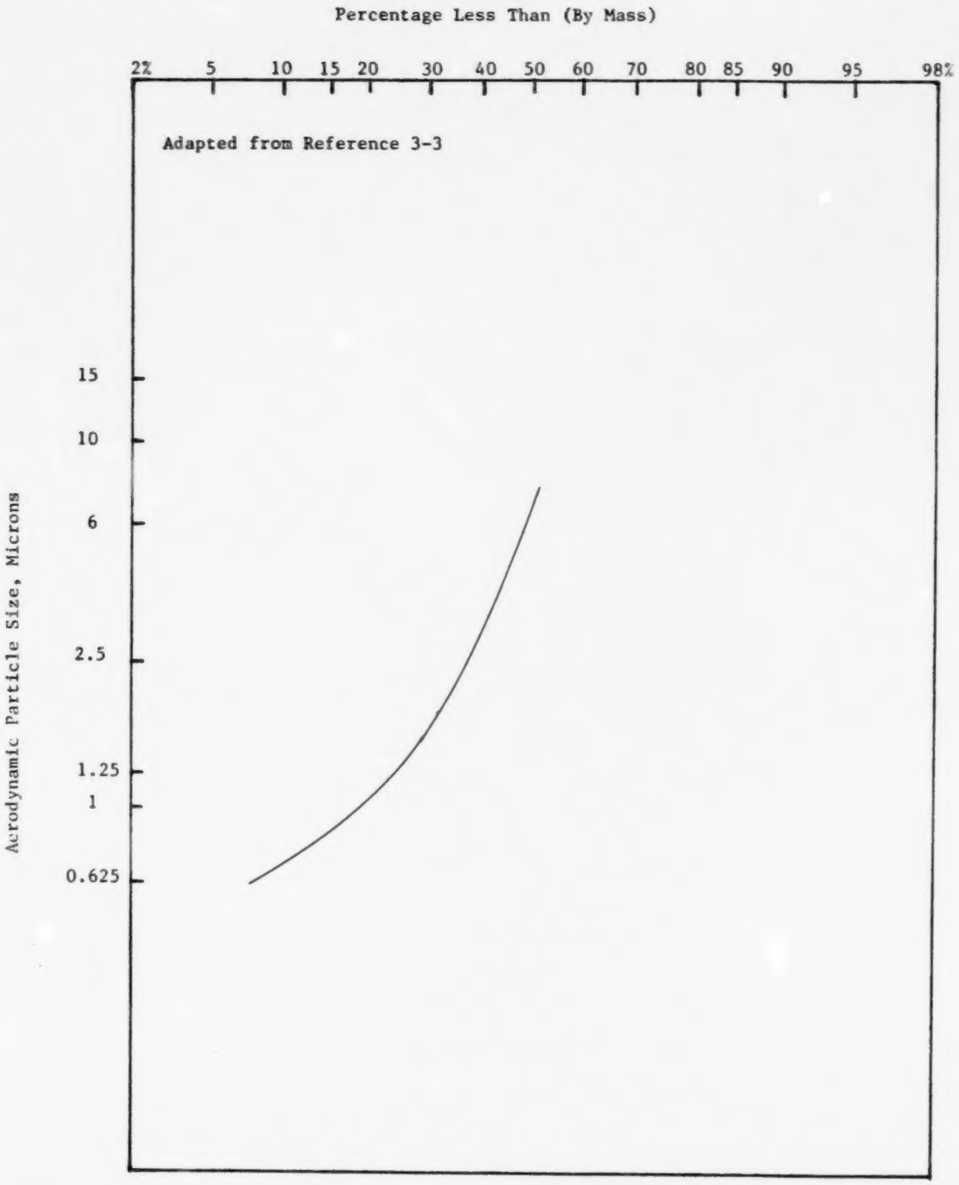


Figure 3-10. Cumulative size distribution for ESP controlled emissions from a recovery furnace (DCE) at site "54".

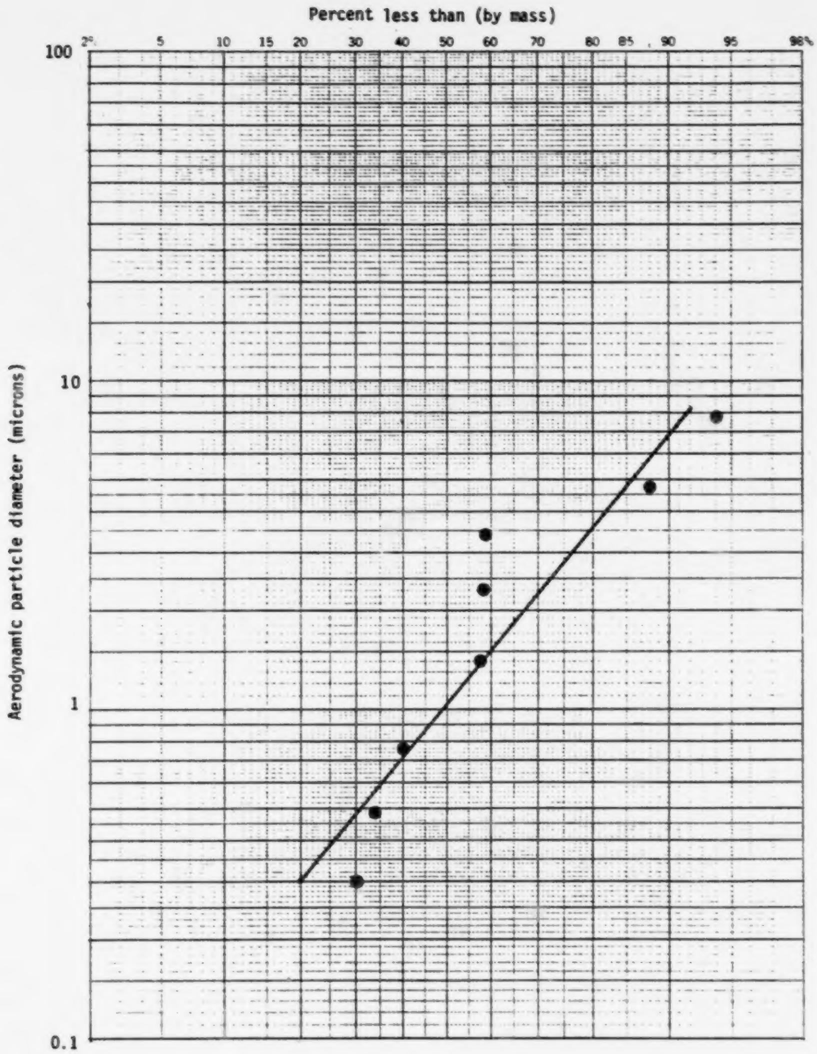


Figure 3-11. Cumulative size distribution for ESP controlled emissions from a recovery furnace (DCE) (site not identified).[3-4]

TABLE 3-8. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED EMISSIONS FROM A RECOVERY FURNACE (DCE)

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "54"	3-3	100.0	--	--	48.0	35.0	25.0	18.5	7.0
Unspecified	3-4	100.0	--	--	88.5	72.5	56.0	50.0	37.5
Mean		100.0	--	--	68.2	53.8	40.5	34.2	22.2

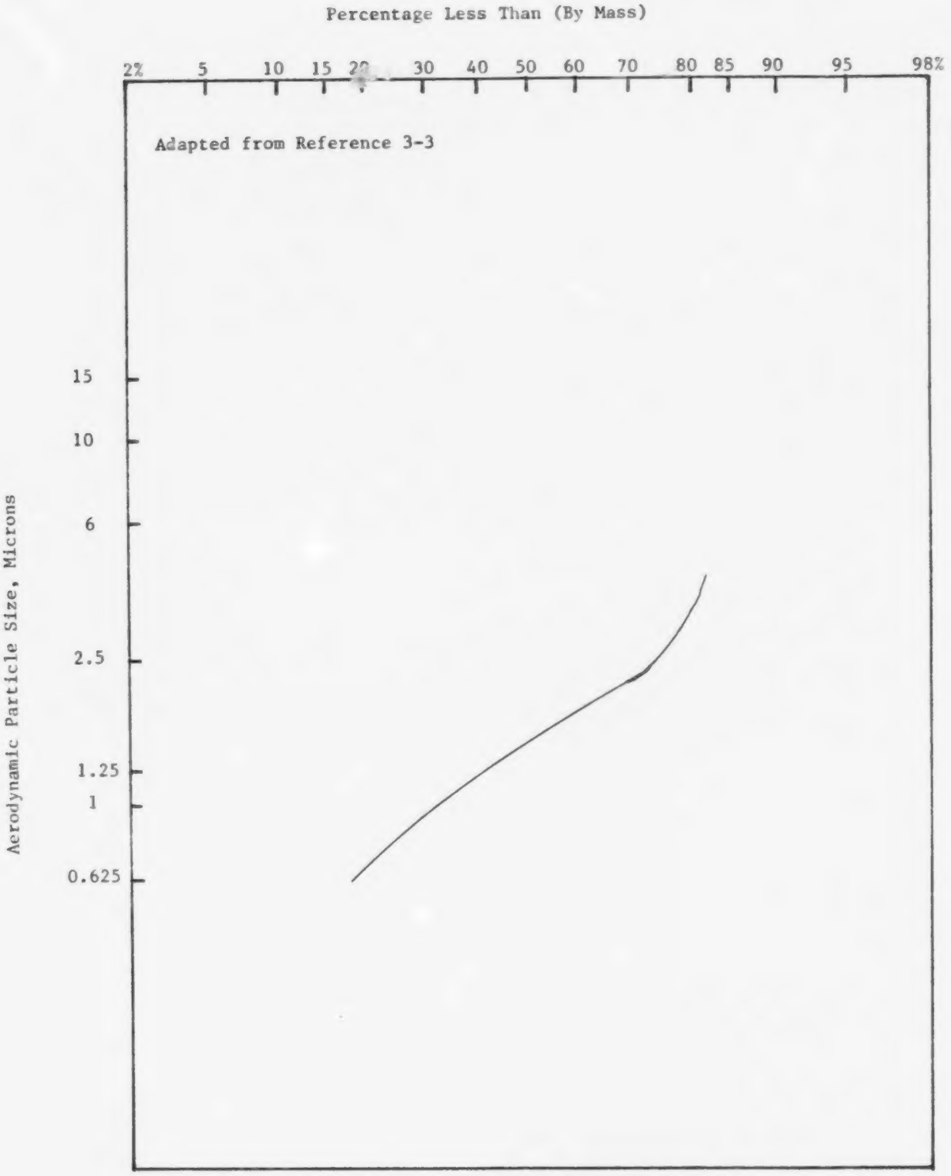


Figure 3-12. Cumulative size distribution for uncontrolled emissions from a recovery furnace (non-DCE) at site "47".

TABLE 3-9. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A RECOVERY FURNACE (NON-DCE)

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "47"	3-3,3-5	100.0	--	--	--	73.0	40.0	30.0	17.0

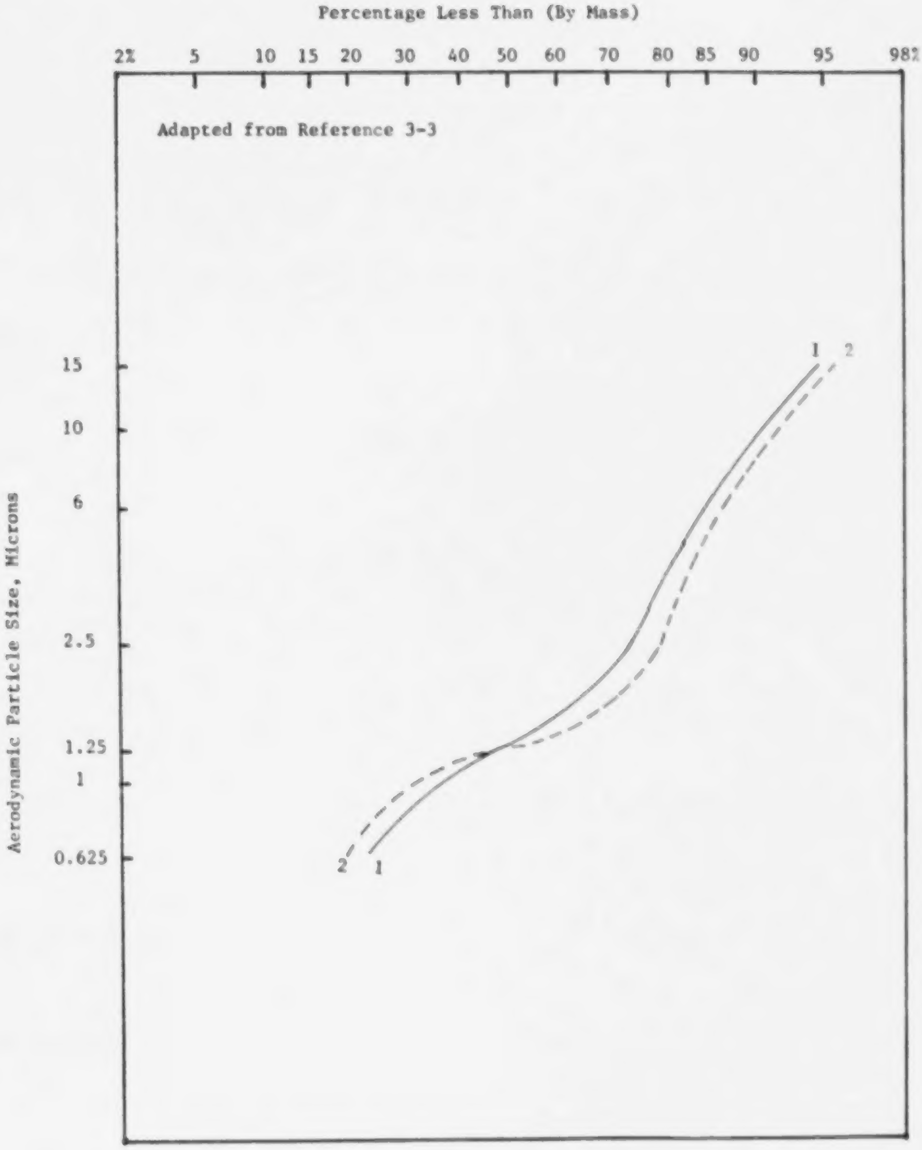


Figure 3-13. Cumulative size distribution for ESP controlled emissions from a recovery furnace (non-DCE) at site "56".

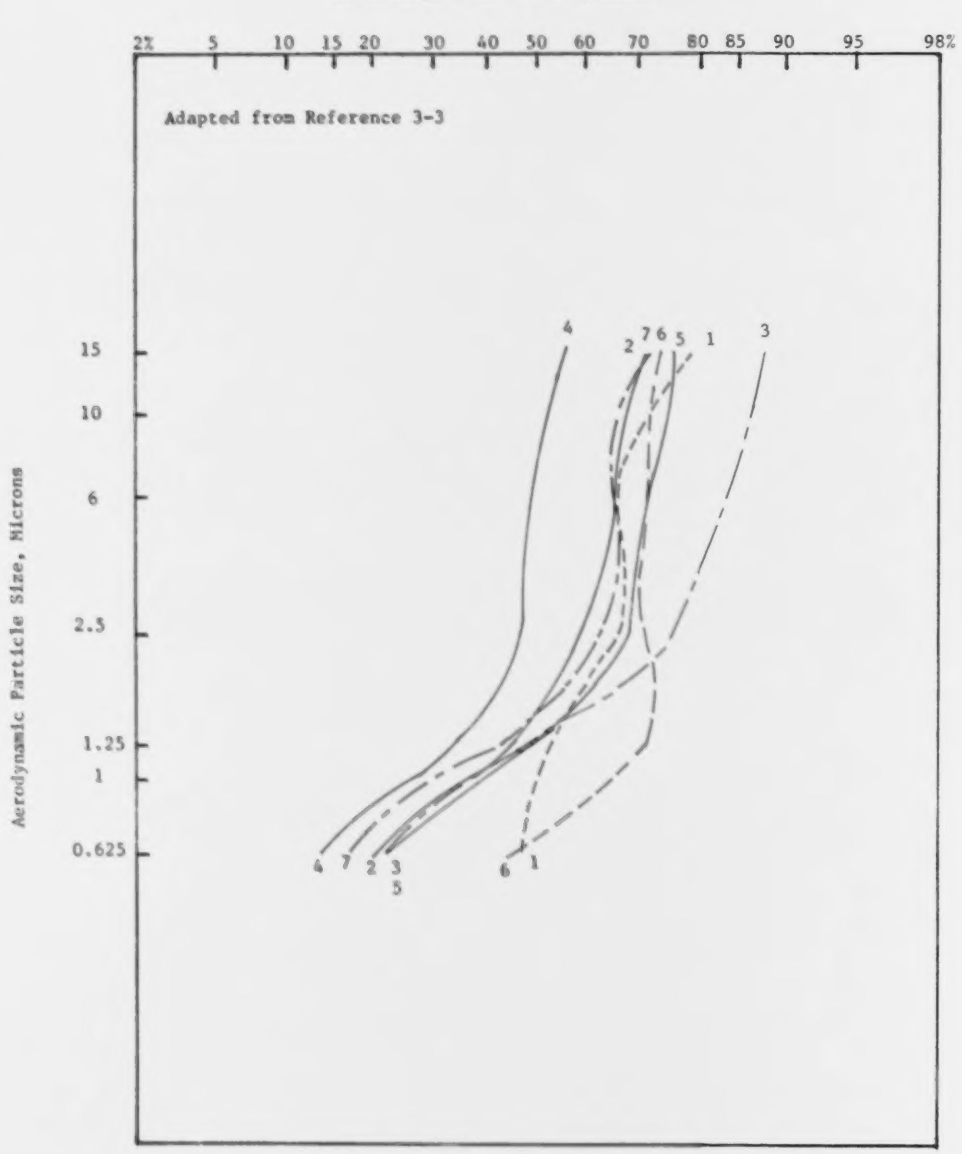


Figure 3-14. Cumulative size distribution for ESP controlled emissions from a recovery furnace (non-DCE) at site "57".

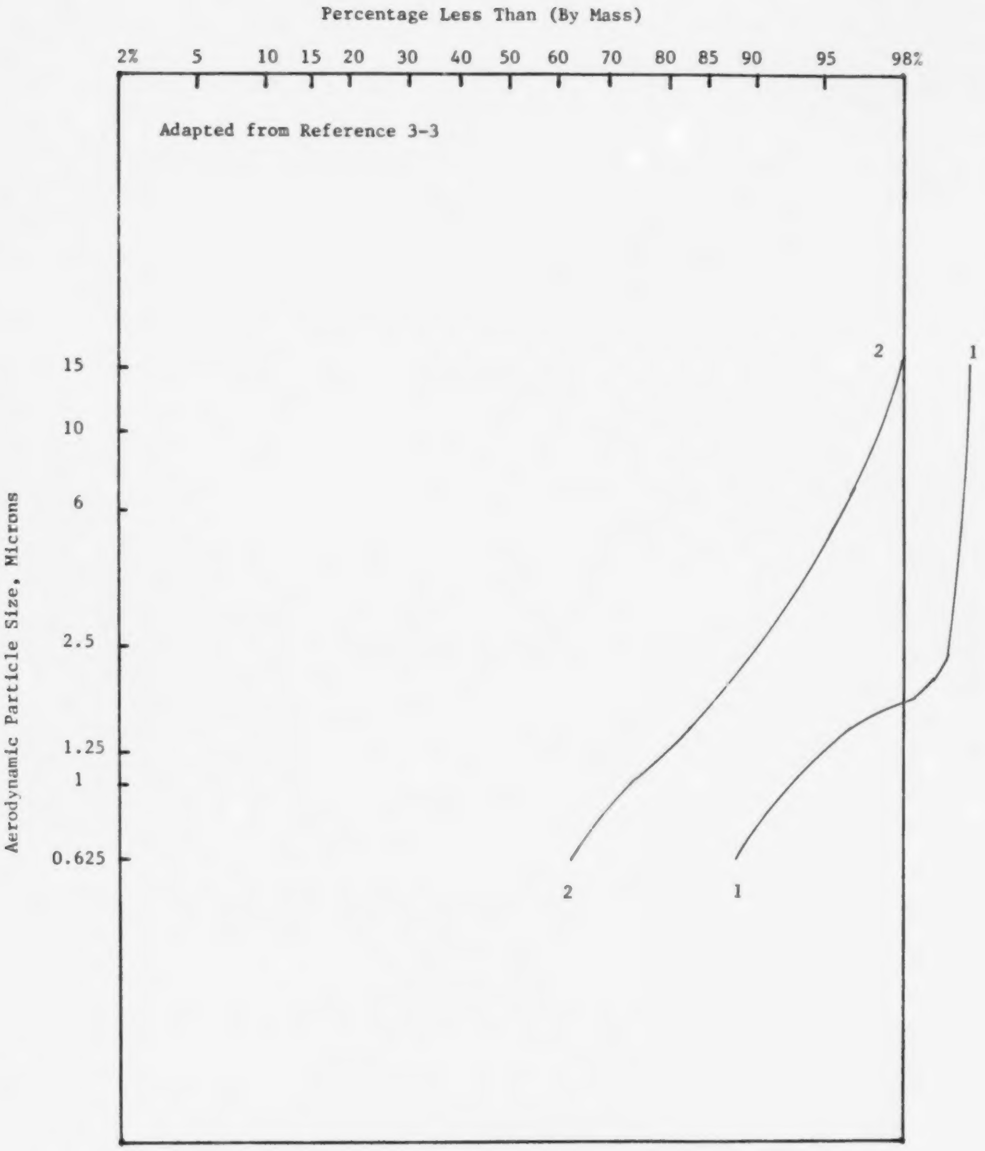


Figure 3-15. Cumulative size distribution for ESP controlled emissions from a recovery furnace (non-DCE) at site "58".

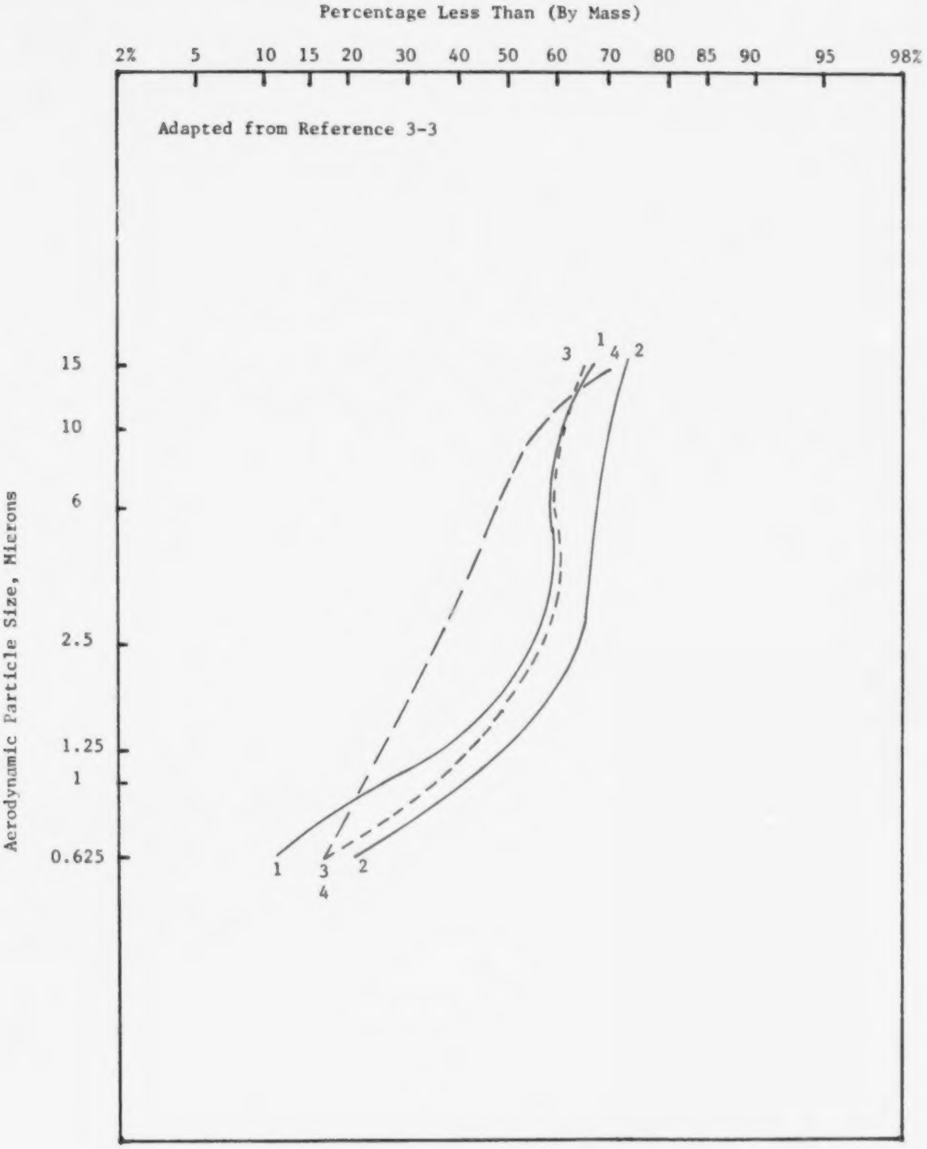


Figure 3-16. Cumulative size distribution for ESP controlled emissions from a recovery furnace (non-DCE) at site "59".

The data for non-DCE recovery furnaces is summarized in Table 3-10. The arithmetic mean was calculated for the cut points of concern for emissions from non-DCE recovery furnaces controlled with ESP's.

Lime Kiln -- Uncontrolled Emissions

Figure 3-17 presents the results of five tests performed on a lime kiln with the venturi scrubber not functioning.[3-3] The results for tests 1, 2, 4, and 5 were obtained with the Mark I cascade impactor while the results for test 3 were obtained with a Mark III cascade impactor. The data are summarized in Table 3-11.

Lime Kiln -- Controlled Emissions

Particle size distribution data are available for a lime kiln whose emissions are controlled with a venturi scrubber and for a lime kiln equipped with an ESP.

The lime kiln with the venturi scrubber was sampled on four occasions with a modified University of Washington cascade impactor employing a heat tape to provide heating to the impactor.[3-3] The results of the four tests are shown in Figure 3-18 and summarized in Table 3-12.

The lime kiln with an ESP actually is three lime kilns exhausting to a common two-chamber, four-field ESP. Four tests, whose results are shown in Figure 3-19, were made using a Mark III cascade impactor. The cut points of concern are summarized in Table 3-13.

Smelt Dissolving Tank Vents -- Uncontrolled Emissions

Two tests were made to determine uncontrolled particle size distributions from a smelt dissolving tank vent.[3-3] The results shown in Figure 3-20 were obtained using the Mark II cascade impactor. The data are summarized in Table 3-14.

Smelt Dissolving Tank Vents -- Controlled Emissions

Data were available for particle size distributions from a smelt dissolving tank vent equipped with a packed tower and for a tank equipped with a venturi scrubber.

The modified Mark III cascade impactor was used to obtain the results shown in Figure 3-21[3-3] for the smelt dissolving tank with a packed tower. The results are summarized in Table 3-15.

The same modified Mark III cascade impactor was used to obtain the results presented in Figure 3-22.[3-3] The tank in this case was equipped with

TABLE 3-10. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED EMISSIONS FROM A RECOVERY FURNACE (NON-DCE)

Source	Reference	Cumulative percent less than							
		Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "56"	3-3	100.0	95.0	90.5	85.5	75.0	50.0	36.5	24.0
		100.0	96.0	92.0	88.0	79.5	50.0	31.0	21.0
Unspecified "57"	3-3	100.0	78.0	72.5	66.0	66.0	52.0	51.0	48.0
		100.0	71.0	68.0	66.0	59.0	45.0	35.0	20.0
		100.0	88.0	86.0	83.6	75.5	46.0	37.0	22.0
		100.0	56.0	51.5	49.6	57.6	33.0	26.0	13.0
		100.0	76.5	74.5	72.0	67.5	50.0	40.0	22.0
		100.0	74.0	72.5	72.0	72.0	72.0	64.5	45.0
		100.0	72.5	66.0	66.0	62.5	42.0	30.0	16.5
Unspecified "58"	3-3	100.0	99.0	99.0	99.0	98.5	95.5	93.0	89.0
		100.0	98.0	97.5	96.0	91.0	80.0	73.0	63.0
Unspecified "59"	3-3	100.0	67.0	62.0	59.0	56.0	36.0	26.5	11.0
		100.0	73.5	71.0	68.0	66.0	50.0	40.0	21.5
		100.0	66.0	62.5	60.0	58.0	42.5	35.0	17.0
		100.0	71.0	56.0	48.0	35.0	26.0	23.0	17.0
Mean		100.0	78.8	74.8	71.9	67.3	51.3	42.4	29.6

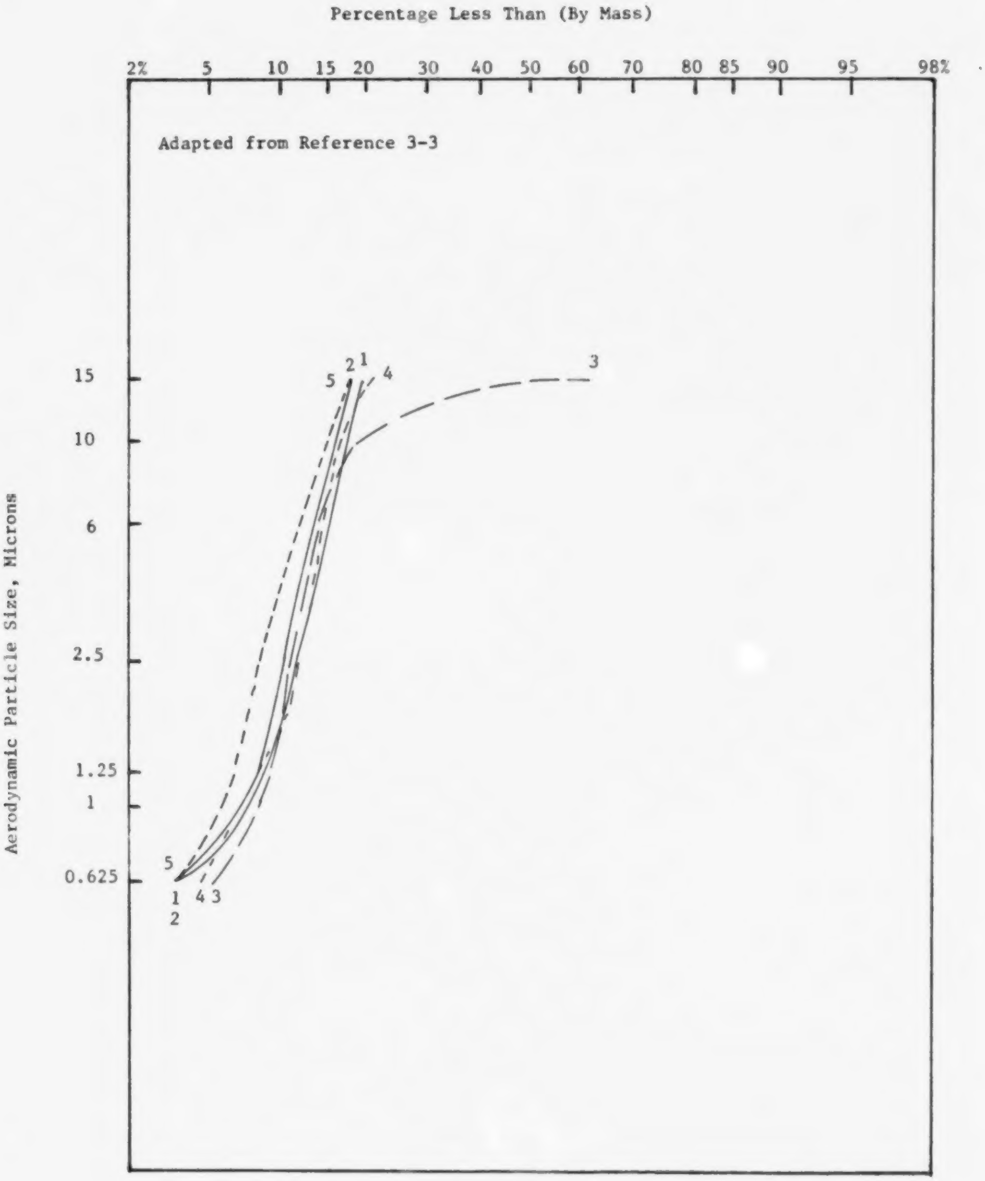


Figure 3-17. Cumulative size distribution for uncontrolled emissions from a lime kiln at site "61".

TABLE 3-11. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A LIME KILN

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "61"	3-3	100.0	19.5	17.0	14.5	11.5	8.5	7.5	3.5
		100.0	18.0	16.0	13.0	10.5	8.0	7.0	3.5
		100.0	62.5	19.0	14.0	11.0	9.5	8.5	5.5
		100.0	20.5	17.0	14.0	11.5	8.5	7.0	5.5
		100.0	18.0	15.0	11.5	8.0	6.5	5.5	3.5
Mean		100.0	27.7	16.8	13.4	10.5	8.2	7.1	3.9

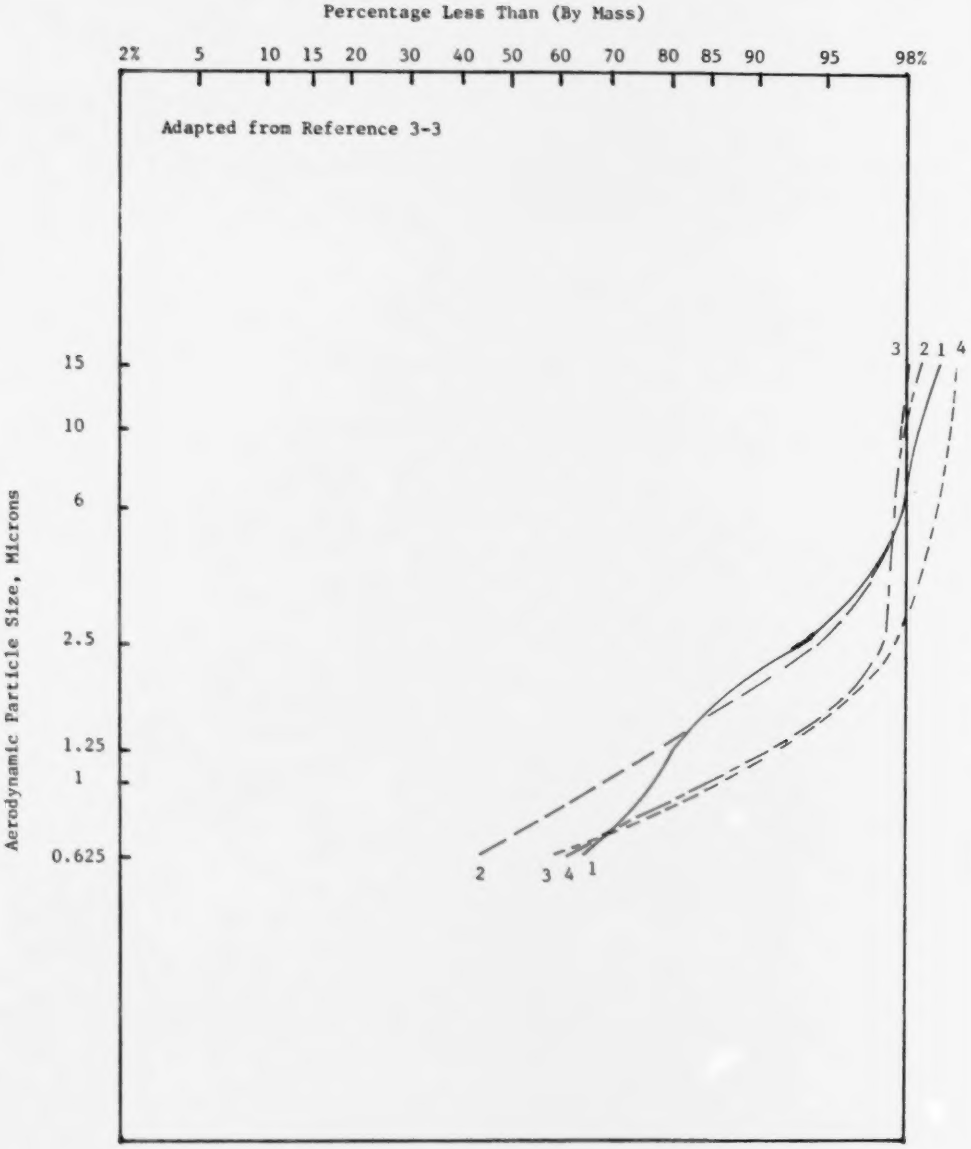


Figure 3-18. Cumulative size distribution for venturi scrubber controlled emissions from a lime kiln at site "62".

TABLE 3-12. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR VENTURI SCRUBBER CONTROLLED EMISSIONS FROM A LIME KILN

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "62"	3-3	100.0	99.0	98.5	98.0	94.0	80.0	77.0	--
		100.0	98.5	98.0	98.0	94.5	77.5	67.5	44.0
		100.0	99.5	99.0	99.0	98.0	91.5	86.0	57.5
		100.0	98.5	98.0	98.0	97.5	91.0	85.0	61.5
Mean		100.0	98.9	98.3	98.2	96.0	85.0	78.9	54.3

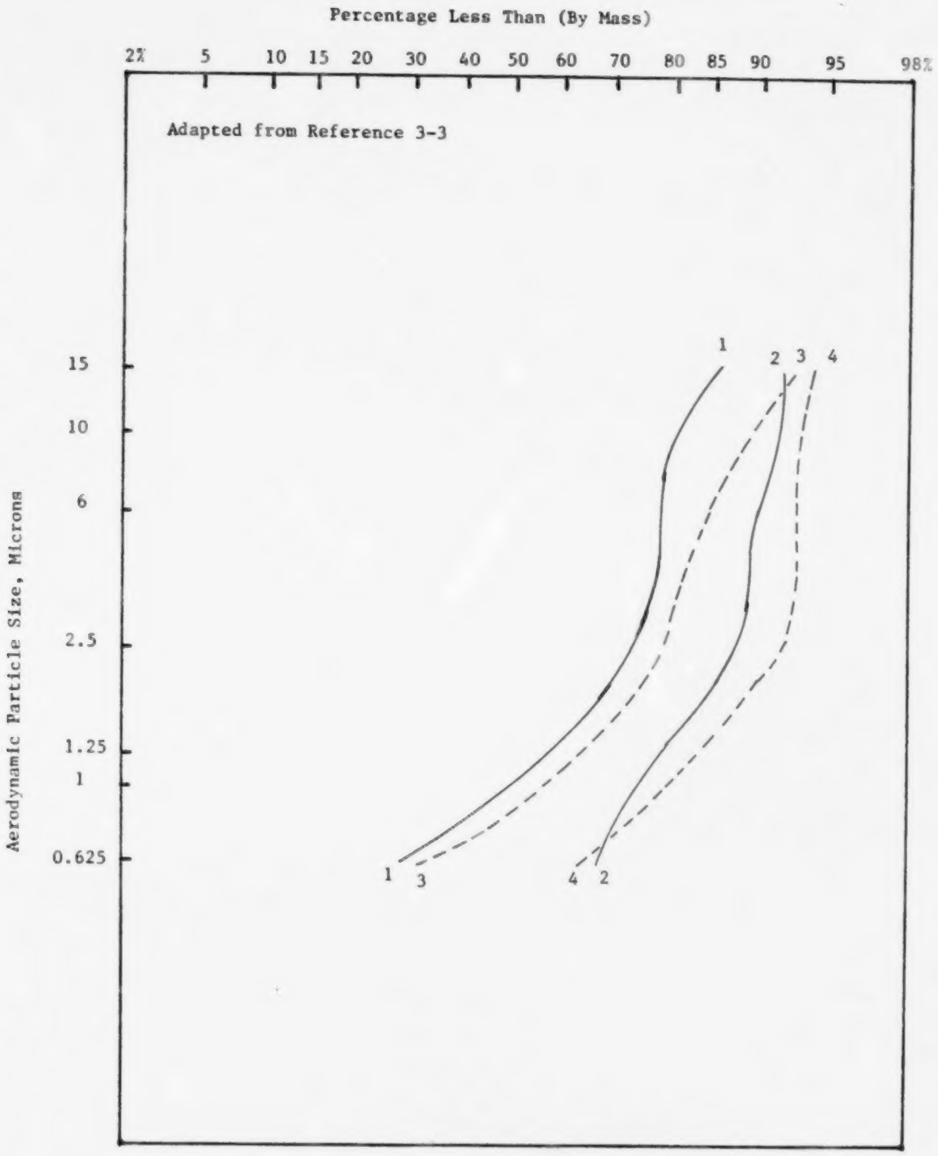


Figure 3-19. Cumulative size distribution for ESP controlled emissions from a lime kiln at site "63".

TABLE 3-13. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED EMISSIONS FROM A LIME KILN

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "63"	3-3	100.0	86.0	80.0	77.5	73.5	57.0	47.0	28.0
		100.0	92.0	91.5	90.0	88.0	78.0	73.5	66.5
		100.0	93.0	89.5	85.5	78.5	62.0	52.5	30.5
		100.0	94.0	93.0	93.0	92.0	84.0	78.5	62.5
Mean		100.0	91.2	88.5	86.5	83.0	70.2	62.9	46.9

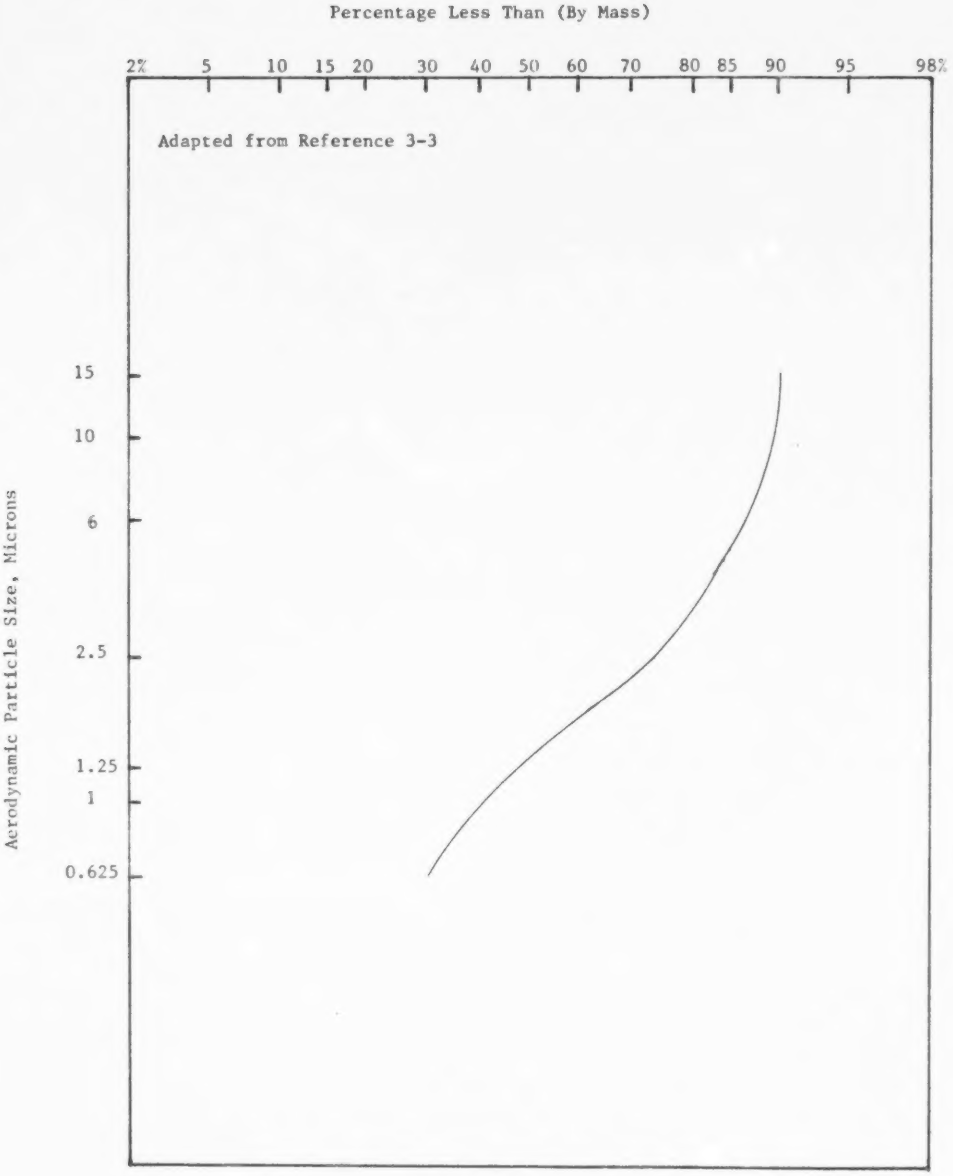


Figure 3-20. Cumulative size distribution for uncontrolled emissions from a smelt dissolving tank vent at site "64".

TABLE 3-14. SUMMARY OF PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A SMELT DISSOLVING TANK VENT

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "64"	3-3	100.0	90.0	88.5	87.0	73.0	47.5	40.0	25.5

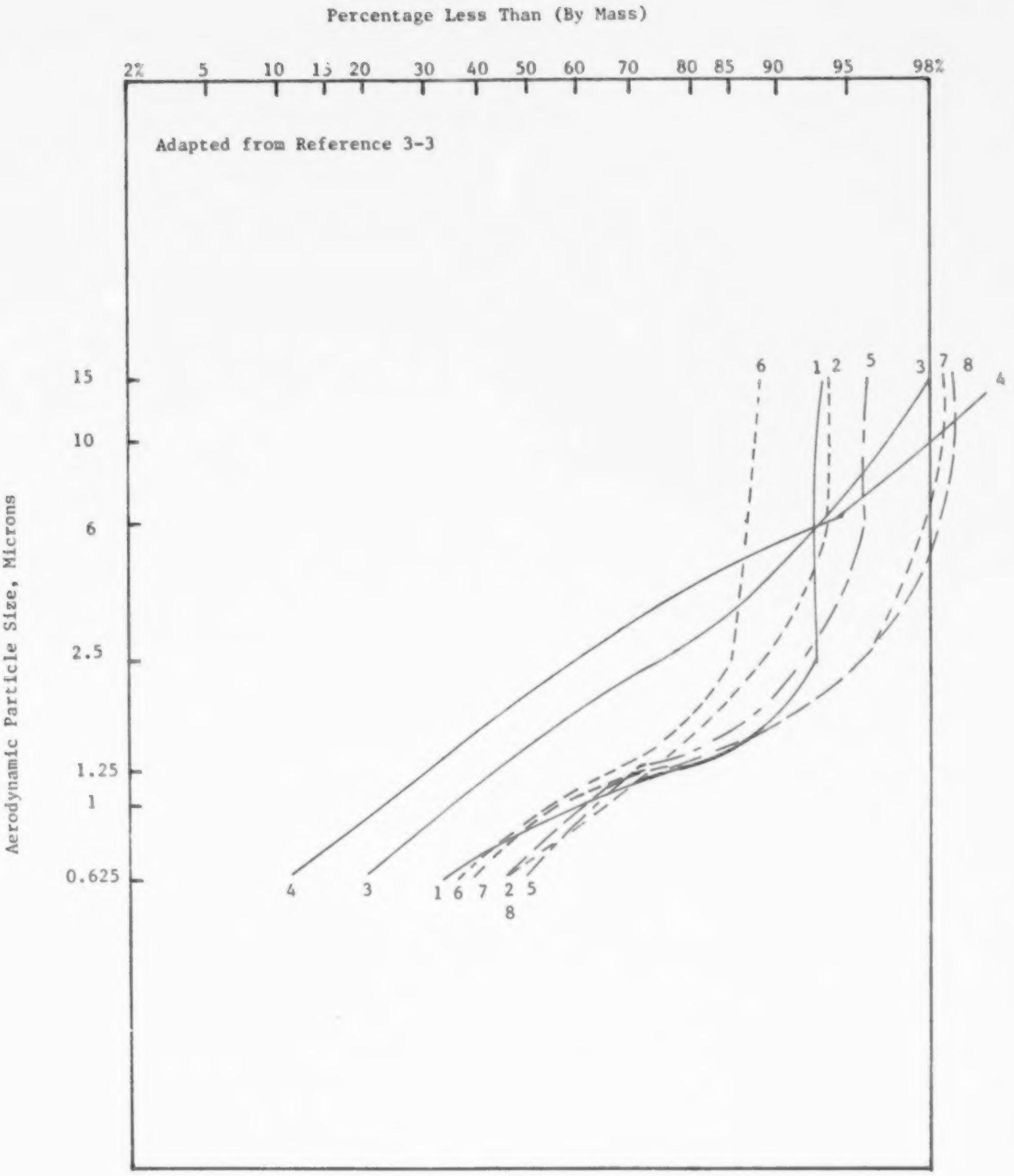


Figure 3-21. Cumulative size distribution for packed tower controlled emissions from a smelt dissolving tank vent at site "65".

TABLE 3-15. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR PACKED TOWER CONTROLLED EMISSIONS FROM A SMELT DISSOLVING TANK

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "65"	3-3	100.0	93.5	93.0	93.0	93.0	76.0	62.0	32.0
		100.0	94.0	94.0	94.0	89.0	76.0	67.0	43.0
		100.0	98.0	97.0	94.0	70.0	43.0	35.0	20.0
		100.0	--	98.0	94.0	61.0	30.0	22.0	10.5
		100.0	96.0	96.0	96.0	91.5	72.0	64.0	49.0
		100.0	88.5	88.0	87.5	85.0	67.0	57.0	36.0
		100.0	98.5	98.5	98.0	96.0	72.0	62.0	39.0
		100.0	98.5	98.5	98.0	96.0	74.0	65.0	44.5
Mean		100.0	95.3	95.3	94.3	85.2	63.8	54.2	34.2

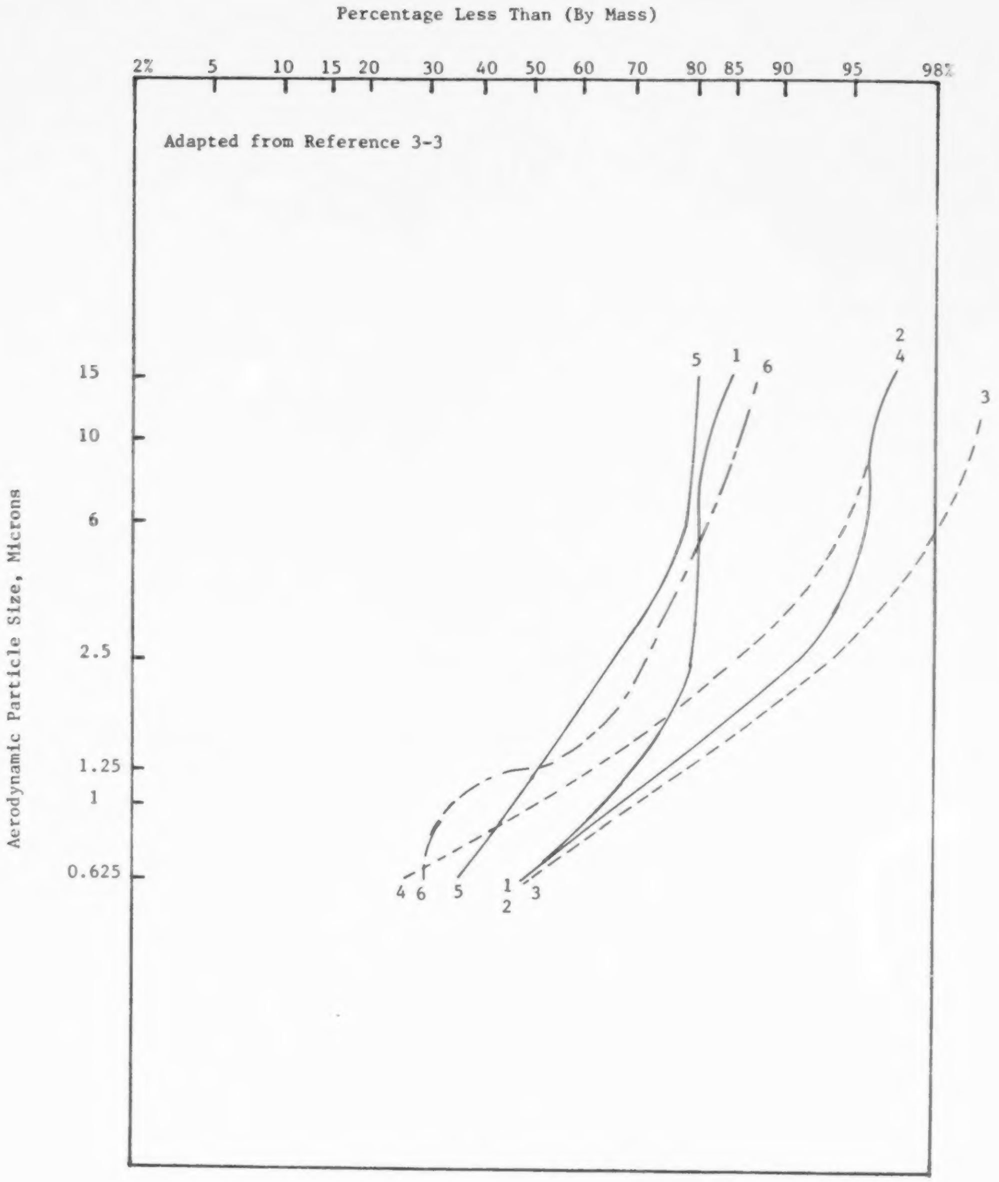


Figure 3-22. Cumulative size distribution for venturi scrubber controlled emissions from a smelt dissolving tank vent at site "66".

a high energy venturi scrubber operating at 16 in. of water (4×10^3 Pa) pressure drop. The cut points of concern are summarized in Table 3-16.

Emission Factor Calculations

As mentioned earlier, there are insufficient process and production data for the size distributions presented in this section, to calculate cumulative size specific emission factors directly. However, emission factors can be calculated by applying the mean cumulative percentages for each cut point to the mass emission factor presented in AP-42. Example:

- Source: DCE recovery furnace
- Emissions: Uncontrolled
- Mean particle size distribution

Mean cumulative percent less than							
Total	15 µm	12 µm	6 µm	2.5 µm	1.2 µm	1.00 µm	0.625 µm
100.0	95.0	93.5	92.2	83.5	56.5	45.3	26.5

- Mass emission factor:[3-1] 50 lb/ton of air dried pulp
- Assumption: During the tests, the uncontrolled emissions from the recovery furnaces were approximately equal to the mass emission factor
- Size specific emission factors (EF)*

$$\begin{aligned} EF_{15\mu m} &= \text{mass emission factor} \times \frac{\text{Mean cumulative percentage Less than 15 } \mu m}{100} \\ &= 150 \text{ lb/ton} \times 95.0/100 \\ &= 142 \text{ lb/ton} \end{aligned}$$

---

*To convert to kilograms per megagram, multiply by 0.5.

TABLE 3-16. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR VENTURI SCRUBBER CONTROLLED EMISSIONS FROM A SMELT DISSOLVING TANK VENT

		Cumulative percent less than							
Source	Reference	Total	15 μm	10 μm	6 μm	2.5 μm	1.25 μm	1.00 μm	0.625 μm
Unspecified "66"	3-3	100.0	85.0	81.0	81.0	80.0	71.0	63.5	48.0
		100.0	97.0	96.0	96.0	92.0	75.0	67.0	48.0
		100.0	--	99.0	98.5	93.0	77.0	68.5	49.0
		100.0	97.0	96.0	95.0	85.0	62.0	50.0	25.0
		100.0	80.5	80.0	78.5	66.0	51.0	46.0	35.0
		100.0	--	85.0	81.5	72.0	45.0	33.0	27.0
Mean		100.0	89.9	89.5	88.4	81.3	63.5	54.7	38.7

Similarly

$EF_{10\mu m} = 140$ lb/ton

$EF_{6\mu m} = 138$ lb/ton

$EF_{2.5\mu m} = 125$ lb/ton

$EF_{1.25\mu m} = 85$ lb/ton

$EF_{1.00\mu m} = 68$ lb/ton

$EF_{0.625\mu m} = 40$ lb/ton

The cumulative size specific emission factors thus calculated are summarized in Table 3-17. For each source, the uncontrolled and controlled emission factors are given as well as the mass emission factor upon which the size specific emission factors are based. Figures 3-23 through 3-28 graphically depict the cumulative size specific emission factors.

3.3 OTHER EMISSION DATA

During the literature search other cumulative size specific emission factor and particle size distribution data were found, but were judged unsatisfactory for analysis. These data are summarized in Table 3-18.

Recovery Boiler, Hoerner Waldorf Mill

Data on a series of tests performed on a recovery boiler at the Hoerner Waldorf Mill are available in Fine Particle Emission Information System (FPEIS).[3-1] It was noted in the data that the "operating parameters changed frequently during the test period." In addition, data were not available on the feed material or feedrate. Because of the uncertainty in operating conditions, it was decided not to include the data in the report at this time.

Recovery Boiler, Confidential Source

Based upon the data presented in the FPEIS report,[3-12] it appeared that the data were obtained under nonisokinetic conditions. Until the isokineticity can be reviewed or references can be located attesting to proper sampling conditions, the data are not acceptable for this report.

Recovery Boiler, Confidential Source

Similar doubts regarding the isokineticity of the data presented in test series 84[3-12] and, again, the data are not acceptable at this time.

TABLE 3-17. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION AND CUMULATIVE SIZE SPECIFIC EMISSION FACTORS

			Cumulative percent less than[a]							
Source	Control device	Mass emission factor	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Recovery furnace	Uncontrolled	150 lb/ton[b]	100.0 (150)	95.0 (142)	93.5 (140)	92.2 (138)	83.5 (125)	56.5 (85)	45.3 (68)	26.5 (40)
	ESP	8 lb/ton[b]	100.0 (8.0)	-- --	-- --	68.2 (5.5)	53.8 (4.3)	40.5 (3.2)	34.2 (2.7)	22.2 (1.8)
Recovery furnace (non-DCE)	Uncontrolled	99 lb/ton[c]	100.0 (99)	-- --	-- --	-- --	78.0 (77)	40.0 (40)	30.0 (30)	17.0 (17)
	ESP	1.7 lb/ton[c]	100.0 (1.7)	78.8 (1.3)	74.8 (1.3)	71.9 (1.2)	67.3 (1.1)	51.3 (0.9)	42.4 (0.7)	29.6 (0.5)
Lime kiln	Uncontrolled	45 lb/ton[b]	100.0 (45)	27.7 (12)	16.8 (7.6)	13.4 (6.0)	10.5 (4.7)	8.2 (3.7)	7.1 (3.2)	3.9 (1.8)
	Venturi scrubber	3 lb/ton[b]	100.0 (3)	98.9 (3)	98.3 (2.9)	98.2 (2.9)	96.0 (2.9)	85.0 (2.6)	78.9 (2.4)	54.3 (1.6)
	ESP	3 lb/ton[d]	100.0 (3)	91.2 (2.7)	88.5 (2.7)	86.5 (2.6)	83.0 (2.5)	70.2 (2.1)	62.9 (1.9)	46.9 (1.4)
Smelt dissolving tank vent	Uncontrolled	5 lb/ton[b]	100.0 (5)	90.0 (4.5)	88.5 (4.4)	87.0 (4.3)	73.0 (3.6)	47.5 (2.4)	40.0 (2.0)	25.5 (1.3)
	Packed tower	1 lb/ton[b]	100.0 (1)	95.3 (0.95)	95.3 (0.95)	94.3 (0.94)	85.2 (0.85)	63.8 (0.64)	54.2 (0.54)	34.2 (0.34)
	Venturi scrubber	0.13 lb/ton[c]	100.0 (0.13)	89.9 (0.12)	89.5 (0.12)	88.4 (0.11)	81.3 (0.10)	63.5 (0.08)	54.7 (0.07)	38.7 (0.05)

[a] Numbers in parentheses are size specific emission factors in pounds per ton.

[b] Source: AP-42 Compilation of Air Pollutant Emission Factors.[3-1]

[c] Source: Particulate Mass and Particulate Size Measurements at Representative Kraft Pulp Mills.[3-2]

[d] Assumption that controlled emissions from a venturi scrubber and ESP are comparable. No other data exist.

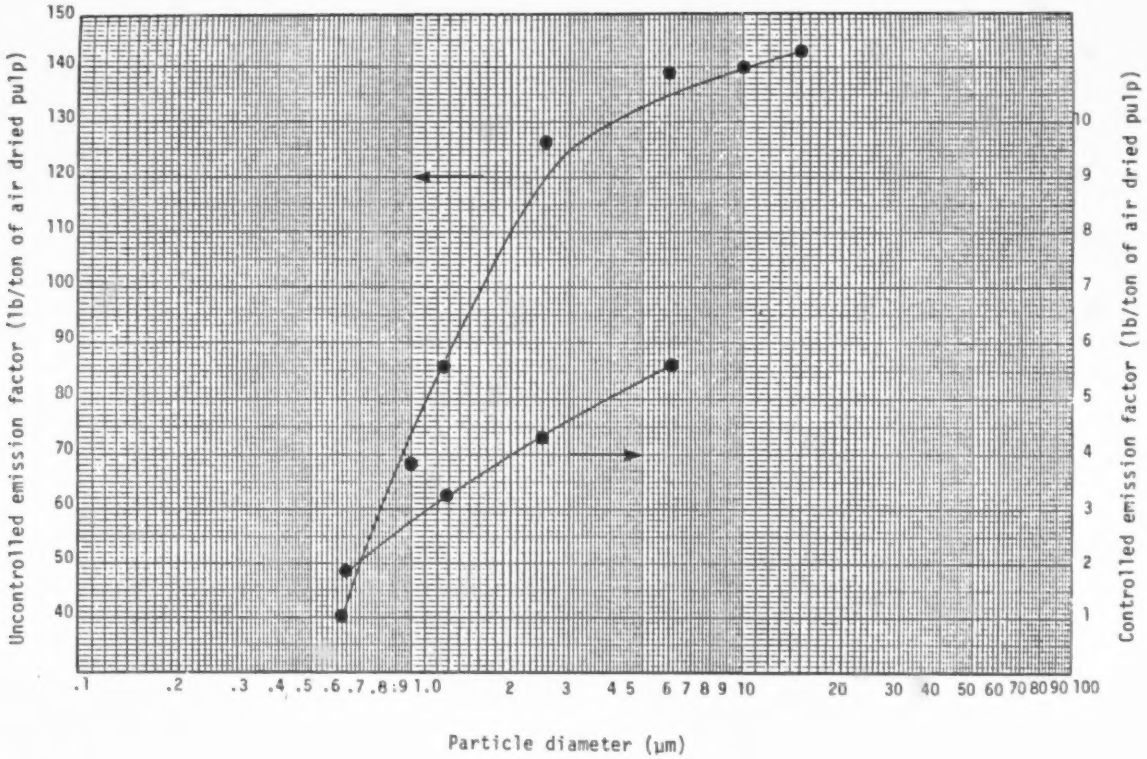


Figure 3-23. Cumulative size specific emission factors for a recovery furnace (DCE) with an ESP.

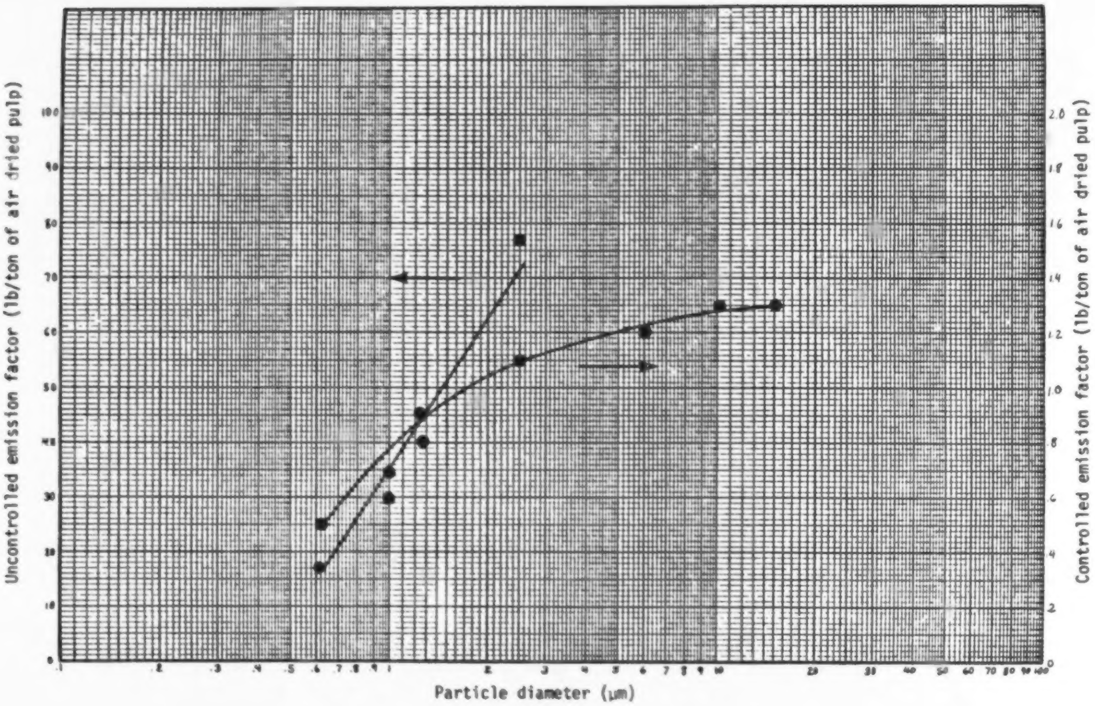


Figure 3-24. Cumulative size specific emission factors for a recovery furnace (non-DCE) with an ESP.

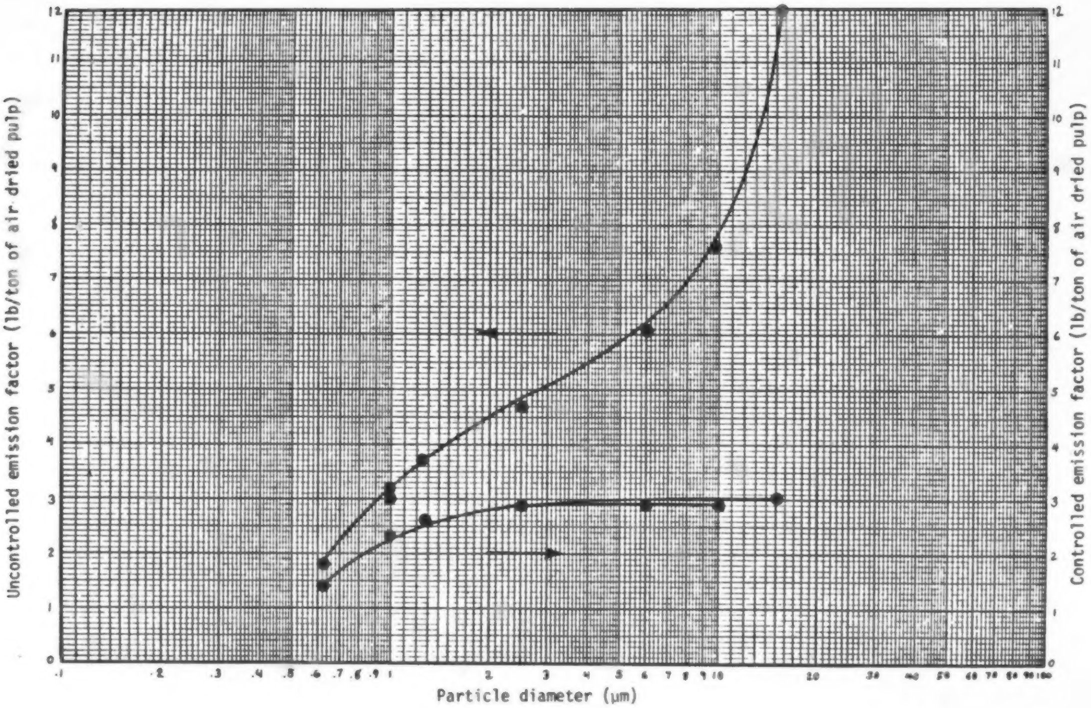


Figure 3-25. Cumulative size specific factors for a lime kiln with a venturi scrubber.

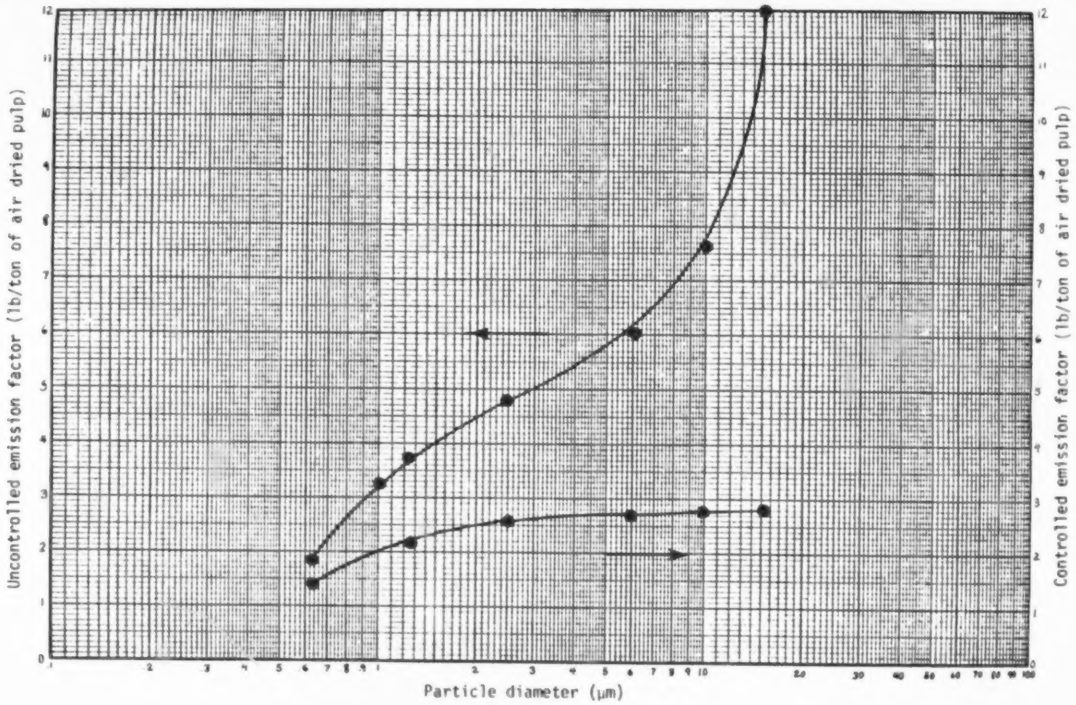


Figure 3-26. Cumulative size specific emission factors for a lime kiln with an ESP.

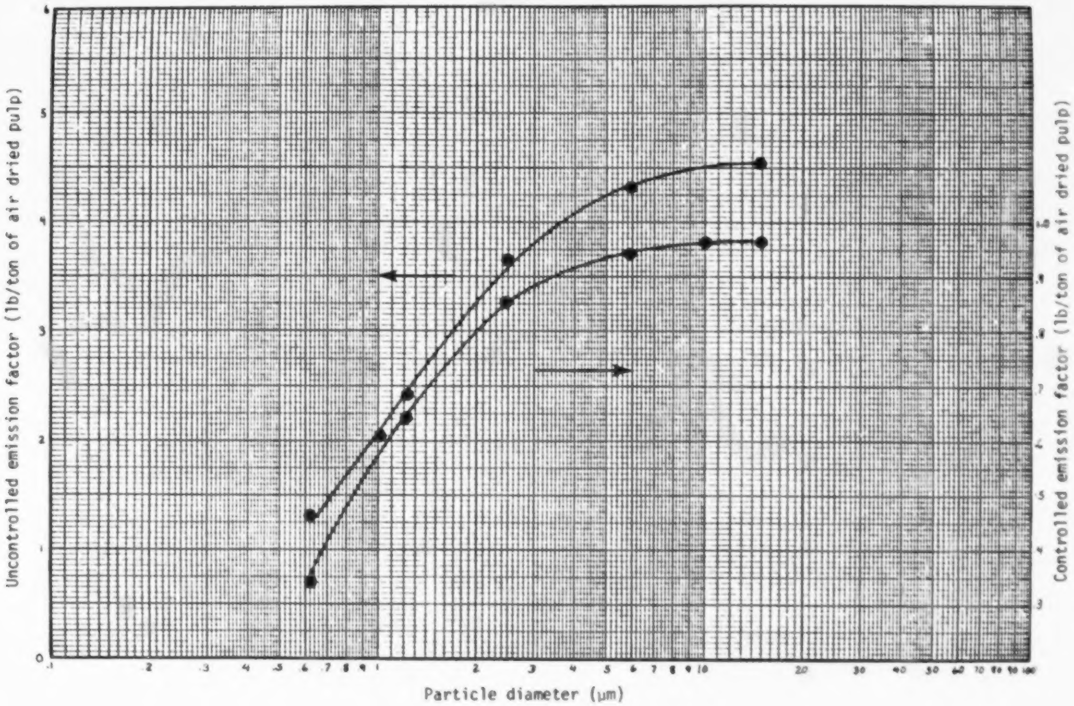


Figure 3-27. Cumulative size specific emission factors for a smelt dissolving tank vent with a packed tower.

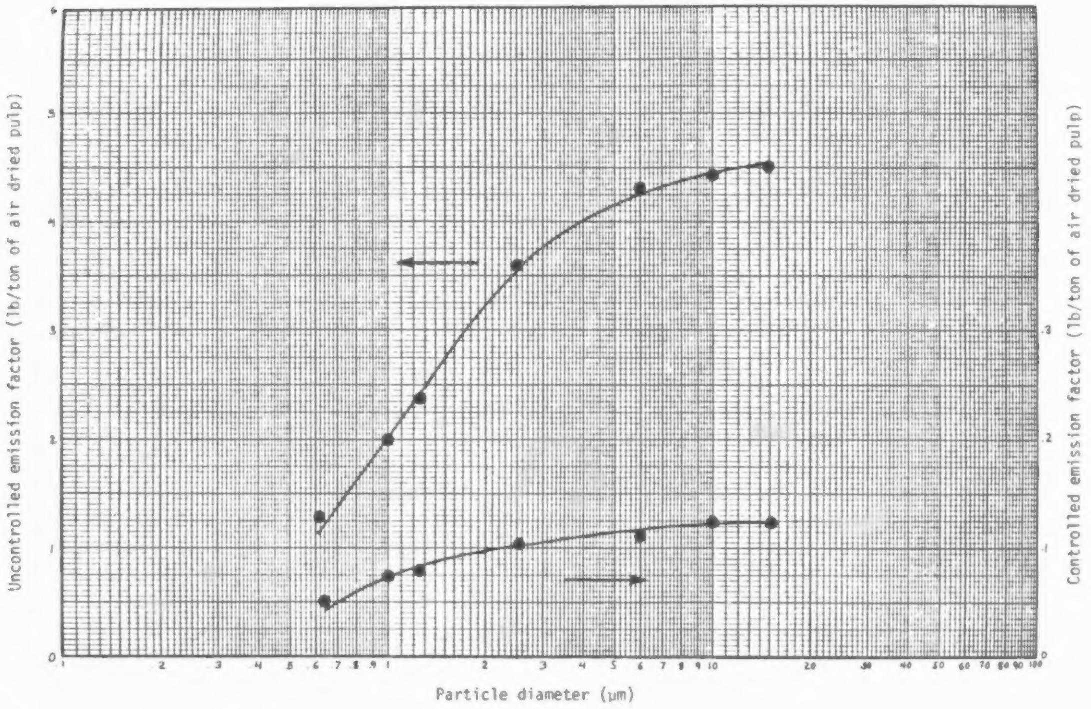


Figure 3-28. Cumulative size specific emission factors for a smelt dissolving tank vent with a venturi scrubber.

TABLE 3-18. SUMMARY OF OTHER EMISSION DATA NOT USED

Emission point	Source	Control device	Type of emission data	Date	Reference
Recovery Boiler	Hoerner Waldorf Mill Missoula, MT	ESP	Uncontrolled and controlled	March to June 1973	3-10
Recovery boiler (DCE)	Confidential	ESP	Uncontrolled and controlled	November 1975	3-11
Recovery boiler (DCE)	Confidential	ESP	Uncontrolled and controlled	December 1975	3-12
Recovery boiler (DCE)	Lonview Fibre Longview, WA	ESP	Controlled	June 1975	3-13
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-14
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-15
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-16
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-17
Smelt dissolving tank vents	St. Regis Paper Company Tacoma, WA	Ducon wetted fan	Uncontrolled and controlled	September 1981	3-2

Recovery Boiler, Longview Fibre

Insufficient data are presented in test series 148[3-13] to explain the significant differences between subseries runs 1 and 2. Because of that difference it was assumed that operating and/or test conditions changed significantly during the test, and that this change invalidated one or both of the data sets. As it was not possible to determine whether just one run or both were invalidated, the data for both runs were judged unacceptable.

Lime Kiln, Weyerhaeuser

Data from references 3-14 through 3-17 were the results of sampling conducted under the EPA/IERL Mobile Device Test Program. A probe was inserted into the exhaust end of the lime kiln. The gases were ducted off to a mobile baghouse and measurements made before and after the control device. Because the data were obtained on a slipstream, the results may not be truly representative. Therefore, the data were not analyzed to obtain cumulative size specific emission factors.

Smelt Dissolving Tank Vents, St. Regis Paper Company

The data[3-2] presented for the smelt dissolving tank vents were obtained from a series of particulate mass and particle size tests conducted on the two smelt dissolving tanks for the no. 4 recovery furnace at St. Regis Paper Company. The data has been presented in this report because:

- Uncontrolled emission tests were performed at the same sampling locations as the controlled emissions test, with the scrubber fans turned off but with the water sprays left on due to plant personnel error
- Each test consists of simultaneous testing of two ducts (east and west). Although the combined totals for most of the data were consistent from test to test, there were considerable differences between the two ducts.

3.4 CONCLUSIONS

Cumulative size specific emission factors based upon A-ranked data were compared to those that were based upon B-ranked data. Upon comparison it was evident that there was great inconsistency between the cumulative emission factors derived with the SoRI two-cyclone train (the A-ranked data) and the factors derived from cascade impactor data (primarily B-ranked data).

Cumulative size specific emission factors based upon B-ranked data were chosen as being more representative because:

- Significantly more tests were made using the cascade impactor
- The tests represented conditions at more than one site
- At least part of the data has been published and subject to review and comment

Therefore, the cumulative emission factors included in the proposed AP-42 section on kraft pulp mills are based upon B-ranked data. As a result, the emission factors have been assigned a C rating.

References for Section 3

3-1. Compilation of Air Pollutant Emission Factors, Third Edition, U. S. Environmental Protection Agency, AP-42, April 1981.

3-2. R. Best, Particulate Mass and Particulate Size Measurements at Representative Kraft Pulp Mills, Vol. I, EPA-600/X-85-330a, Acurex Corporation, Mountain View, CA, August 1982.

3-3. A Study of Particulate Size Distribution in Emissions from Controlled Sources in the Kraft Process, National Council of the Paper Industry for Air and Steam Improvement, Inc., Technical Bulletin No. 94, May 1978.

3-4. Personal communication, J. Pinkerton, National Council of the Paper Industry for Air and Steam Improvement, Inc. to H. Modetz, Acurex Corporation, September 15, 1982.

3-5. J. Paul, "Application of Electrostatic Precipitators for the Control of Fumes from Low Odor Pulp Mill Recovery Boilers," Journal of the Air Pollution Control Association, p. 158-162, February 1975.

3-6. J. Bosch, M. Pilat, and B. Hrutfiord, "Size Distribution of Aerosols from a Kraft Mill Recovery Furnace," _Journal of the Technical Association of the Pulp and Paper Industry_, p. 1971-1875, November 1971.

3-7. _The Electrostatic Precipitator Manual, Chapter IX, Section 2611-907_, The McIlvaine Company, p. 101.1-103.1, March 1976.

3-8. M. Pilat, D. Ensor, and J. Bosch, "Source Test Cascade Impactor," _Atmospheric Environment, Volume 4_, p. 671-679, 1970.

3-9. S. Larssen, D. Ensor, and M. Pilat, "Relationship of Plume Opacity to the Properties of Particulates Emitted from Kraft Recovery Furnaces," _Journal of the Technical Association of the Pulp and Paper Industry_, p. 88-92, January 1972.

*3-10. FPEIS Test Series 18, U. S. Environmental Protection Agency, May 1982.

*3-11. FPEIS Test Series 83, U. S. Environmental Protection Agency, May 1982.

*3-12. FPEIS Test Series 84, U. S. Environmental Protection Agency, May 1982.

*3-13. FPEIS Test Series 148, U. S. Environmental Protection Agency, May 1982.

*3-14. FPEIS Test Series 104, U. S. Environmental Protection Agency, May 1982.

*3-15. FPEIS Test Series 105, U. S. Environmental Protection Agency, May 1982.

*3-16. FPEIS Test Series 106, U. S. Environmental Protection Agency, May 1982.

*3-17. FPEIS Test Series 107, U. S. Environmental Protection Agency, May 1982.

3-18 FPEIS Computer Printout, Run Identification 30GLJ, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1986.

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*The original reference document for each FPEIS test series is listed in the above reference 3-18.

SECTION 4

CHEMICAL CHARACTERIZATION

Data which presented the specific chemical characteristics of inhalable particulate was not located. However, there are data which generally characterize the fine particulate.

Recovery Furnaces

Bosch et al.[4-1,4-2] reported that makeup of recovery furnace particulate is generally a sodium salt. However, in two cases, the presence of a black ash was noted. Separation of the two materials indicated that the carbonaceous black ash had a mass mean diameter of 30 μm while the sodium salts had a mass mean diameter of 0.9 μm.

Collins et al.[4-2] studied the composition of recovery furnace fine particulate. It was reported that the particulate is 85 percent Na_2SO_4, with lesser quantities of NaCl, Na_3SO_3, and black ash. Collins et al. also reported that enhancement of smelt and ignited black liquor may result in changes to the Na_2SO_4 content.

Subsequent analyses[4-2] on a non-DCE recovery furnace substantiated the work of Collins, et al., with 80 to 90 percent of the fine particulate being Na_2SO_4.

Lime Kilns

Chemical analyses reported uncontrolled lime kiln emissions to be approximately 10 percent sodium salt.[4-3] For a venturi scrubber equipped lime kiln, studies have indicated that roughly 55 to 60 percent of the total particulate exists as Na_2SO_4 with 0.5 to 1 percent calcium salt, and minor burnouts of trace elements.[4-2]

Smelt Dissolving Tank Vent

Minimal data were found on smelt dissolving tank vent emissions. A Na_2SO_4 and Na_2CO_3 composition has been suggested.[4-2]

References for Section 4

4-1. J. Bosch, M. Pilat, and B. Hrutfiord, "Size Distribution of Aerosols From a Kraft Mill Recovery Furnace," Journal of the Technical Association of the Pulp and Paper Industry, p. 1871-1875, November 1971.

4-2. A Study of Particulate Size Distribution in Emissions from Controlled Sources in the Kraft Process, National Council of the Paper Industry for Air and Steam Improvement, Inc., Technical Bulletin No. 94, May 1978.

SECTION 5
PROPOSED AP-42 SECTION

The proposed revision to Section 10.1 of AP-42 is presented in the following pages as it would appear in the actual document.

(Based on external review comments on this source category report, it was determined that additional data needed to be included in developing the emissions factors. The Office of Air Quality Planning and Standards revised the AP-42 section to reflect the external review comments and to incorporate the additional data. Documentation for these revisions which are included in the following AP-42 section is presented in Appendix C.)

10.1 CHEMICAL WOOD PULPING

10.1.1 General

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The four processes principally used in chemical pulping are kraft, sulfite, neutral sulfite semichemical (NSSC), and soda. The first three display the greatest potential for causing air pollution. The kraft process alone accounts for over 80 percent of the chemical pulp produced in the United States. The choice of pulping process is determined by the desired product, by the wood species available, and by economic considerations.

10.1.2 Kraft Pulping

Process Description[1] - The kraft pulping process (See Figure 10.1-1) involves the digesting of wood chips at elevated temperature and pressure in "white liquor", which is a water solution of sodium sulfide and sodium hydroxide. The white liquor chemically dissolves the lignin that binds the cellulose fibers together.

There are two types of digester systems, batch and continuous. Most kraft pulping is done in batch digesters, although the more recent installations are of continuous digesters. In a batch digester, when cooking is complete, the contents of the digester are transferred to an atmospheric tank usually referred to as a blow tank. The entire contents of the blow tank are sent to pulp washers, where the spent cooking liquor is separated from the pulp. The pulp then proceeds through various stages of washing, and possibly bleaching, after which it is pressed and dried into the finished product. The "blow" of the digester does not apply to continuous digester systems.

The balance of the kraft process is designed to recover the cooking chemicals and heat. Spent cooking liquor and the pulp wash water are combined to form a weak black liquor which is concentrated in a multiple effect evaporator system to about 55 percent solids. The black liquor is then further concentrated to 65 percent solids in a direct contact evaporator, by bringing the liquor into contact with the flue gases from the recovery furnace, or in an indirect contact concentrator. The strong black liquor is then fired in a recovery furnace. Combustion of the organics dissolved in the black liquor provides heat for generating process steam and for converting sodium sulfate to sodium sulfide. Inorganic chemicals present in the black liquor collect as a molten smelt at the bottom of the furnace.

The smelt is dissolved in water to form green liquor, which is transferred to a causticizing tank where quicklime (calcium oxide) is added to convert the solution back to white liquor for return to the digester system. A lime mud precipitates from the causticizing tank, after which it is calcined in a lime kiln to regenerate quicklime.

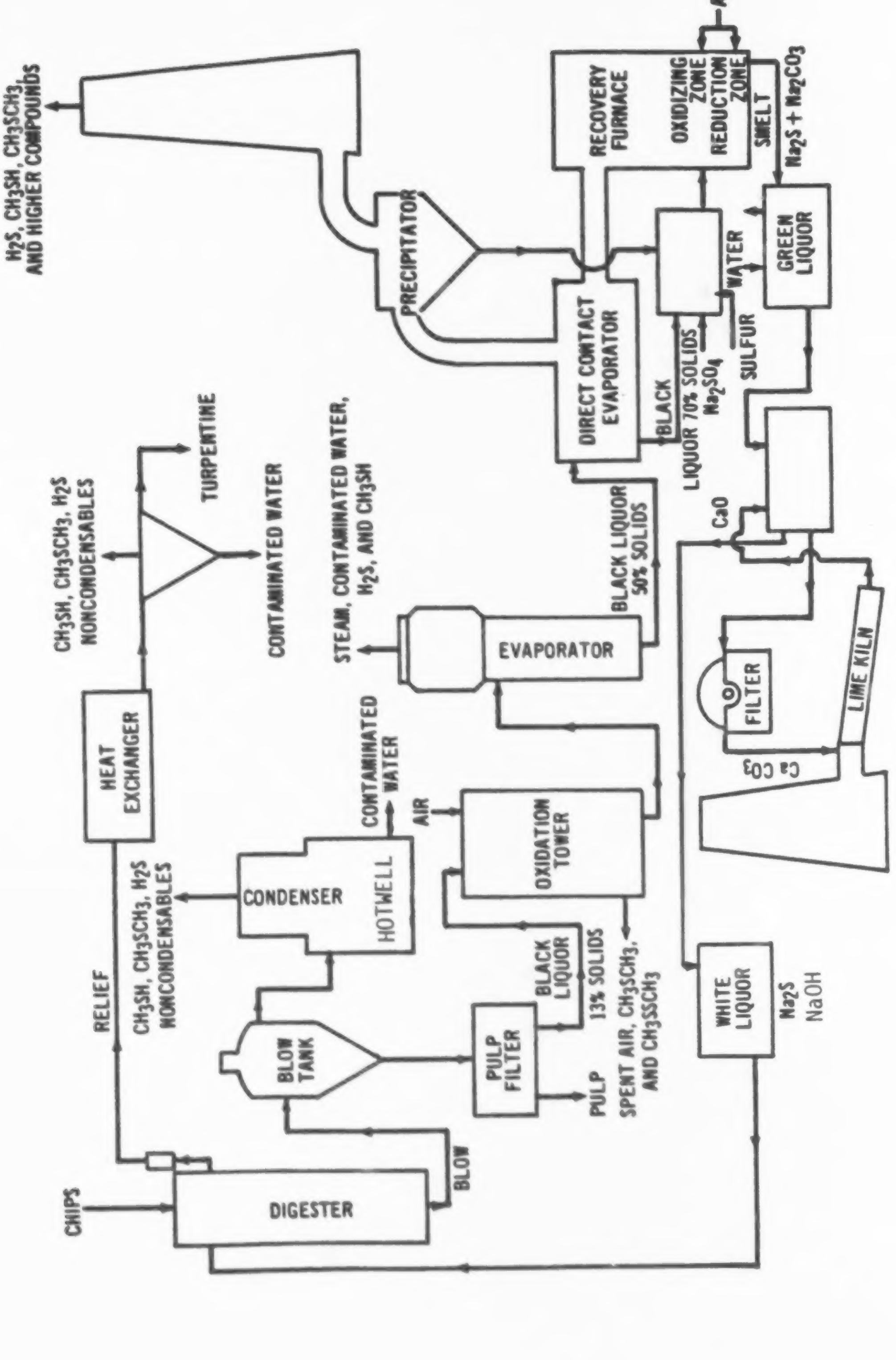
CHIPS
DIGESTER
BLOW
RELIEF
BLOW TANK
PULP FILTER
PULP
CH3SH, CH3SCH3, H2S NONCONDENSABLES
CONDENSER
HOTWELL
CONTAMINATED WATER
BLACK LIQUOR
13% SOLIDS
SPENT AIR, CH3SCH3, AND CH3SSCH3
AIR
OXIDATION TOWER
HEAT EXCHANGER
CH3SH, CH3SCH3, H2S NONCONDENSABLES
TURPENTINE
CONTAMINATED WATER
STEAM, CONTAMINATED WATER, H2S, AND CH3SH
EVAPORATOR
BLACK LIQUOR 50% SOLIDS
DIRECT CONTACT EVAPORATOR
PRECIPITATOR
H2S, CH3SH, CH3SCH3, AND HIGHER COMPOUNDS
BLACK LIQUOR 70% SOLIDS
Na2SO4
SULFUR
WATER
RECOVERY FURNACE
OXIDIZING ZONE
REDUCTION ZONE
AIR
SMELT
Na2S + Na2CO3
GREEN LIQUOR
CaO
FILTER
LIME KILN
Ca CO3
WHITE LIQUOR
Na2S
NaOH

Figure 10.1-1. Typical kraft sulfate pulping and recovery process.

For process heating, for driving equipment, for providing electric power, etc., many mills need more steam than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, or bark and wood are commonly used.

Emissions And Controls[1-7] - Particulate emissions from the kraft process occur largely from the recovery furnace, the lime kiln and the smelt dissolving tank. These emissions are mainly sodium salts, with some calcium salts from the lime kiln. They are caused mostly by carryover of solids and sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills with either a cyclonic scrubber or cascade evaporator as the direct contact evaporator, further control is necessary, as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostatic precipitator is employed after the direct contact evaporator, for an overall particulate control efficiency of from 85 to more than 99 percent. Auxiliary scrubbers may be added at existing mills after a precipitator or a venturi scrubber to supplement older and less efficient primary particulate control devices.

Particulate control on lime kilns is generally accomplished by scrubbers. Electrostatic precipitators have been used in a few mills. Smelt dissolving tanks usually are controlled by mesh pads, but scrubbers can provide further control.

The characteristic odor of the kraft mill is caused by the emission of reduced sulfur compounds, the most common of which are hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyl disulfide, all with extremely low odor thresholds. The major source of hydrogen sulfide is the direct contact evaporator, in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. Indirect contact evaporators can significantly reduce the emission of hydrogen sulfide. The lime kiln can also be a potential source of odor, as a similar reaction occurs with residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensible offgasses from the digesters and multiple effect evaporators.

Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component, lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignin. These compounds are emitted from many points within a mill, but the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally found in kraft mills, emitted sulfur compounds can be reduced by process modifications and improved operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Also, noncondensible odorous gases vented from the digester/blow tank system and multiple effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Efficient operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen, residence time and turbulence, significantly reduces emissions of reduced sulfur compounds from this source as well. The use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions.

Several new mills have incorporated recovery systems that eliminate the conventional direct contact evaporators. In one system, heated combustion air, rather than fuel gas, provides direct contact evaporation. In another, the multiple effect evaporator system is extended to replace the direct contact evaporator altogether. In both systems, sulfur emissions from the recovery furnace/direct contact evaporator can be reduced by more than 99 percent.

Sulfur dioxide is emitted mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs about 75 percent of these emissions, and further scrubbing can provide additional control.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Some nitrogen oxides also are emitted from the recovery furnace and lime kilns, although amounts are relatively small. Indications are that nitrogen oxide emissions are on the order of 0.5 and 1.0 kilograms per air dried megagrams (1 and 2 lb/air dried ton) of pulp produced from the lime kiln and recovery furnace, respectively.[5-6]

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels used are coal, oil, natural gas or bark/wood waste. See Chapter 1 for emission factors for boilers.

Table 10.1-1 presents emission factors for a conventional kraft mill. The most widely used particulate control devices are shown, along with the odor reductions through black liquor oxidation and incineration of noncondensible offgases. Tables 10.1-2 through 10.1-7 present cumulative size distribution data and size specific emission factors for particulate emissions from sources within a conventional kraft mill. Uncontrolled and controlled size specific emission factors[7] are presented in Figures 10.1-2 through 10.1-7. The particle sizes presented are expressed in terms of the aerodynamic diameter.

10.1.3 Acid Sulfite Pulping

Process Description - The production of acid sulfite pulp proceeds similarly to kraft pulping, except that different chemicals are used in the cooking liquor. In place of the caustic solution used to dissolve the lignin in the wood, sulfurous acid is employed. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium or ammonium is used. A diagram of a typical magnesium base process is shown in Figure 10.1-8.

Digestion is carried out under high pressure and high temperature, in either batch mode or continuous digesters, and in the presence of a sulfurous acid/bisulfite cooking liquid. When cooking is completed, either the digester is discharged at high pressure into a blow pit, or its contents are pumped into a dump tank at a lower pressure. The spent sulfite liquor (also called red liquor) then drains through the bottom of the tank and is treated and discarded,

TABLE 10.1-1. EMISSION FACTORS FOR SULFITE PULPING[a]

EMISSION FACTOR RATING: A

Source	Type of control	Particulate		Sulfur dioxide (SO_2)		Carbon monoxide (CO)		Hydrogen sulfide ($S^=$)		RSH, RSR, RSSR ($S^=$)	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Digester relief and blow tank	Untreated[b]	-	-	-	-	-	-	0.02	0.03	0.6	1.2
Brown stock washer	Untreated[b]	-	-	-	-	-	-	0.01	0.02	0.2[c]	0.4[c]
Multiple effect evaporator	Untreated[b]	-	-	-	-	-	-	0.55	1.1	0.05	0.1
Recovery boiler and direct evaporator	Untreated[d]	90	180	3.5	7	5.5	11	6[e]	12[e]	1.5[e]	3[e]
	Venturi scrubber[f]	24	48	3.5	7	5.5	11	6[e]	12[e]	1.5[e]	3[e]
	ESP	1	2	3.5	7	5.5	11	6[e]	12[e]	1.5[e]	3[e]
	Auxiliary scrubber	1.5-7.5[g]	3-15[g]					6[e]	12[e]	1.5[e]	3[e]
Noncontact recovery boiler without direct contact evaporator	Untreated	115	230	-	-	5.5	11	0.05[h]	0.1[h]	-	-
	ESP	1	2	-	-	5.5	11	0.05[h]	0.1[h]	-	-
Smelt dissolving tank	Untreated	3.5	7	0.1	0.2	-	-	0.1[j]	0.2[j]	0.15[j]	0.3[j]
	Mesh pad	0.5	1	0.1	0.2	-	-	0.1[j]	0.2[j]	0.15[j]	0.3[j]
	Scrubber	0.1	0.2	-	-	-	-	0.1[j]	0.2[j]	0.15[j]	0.3[j]
Lime kiln	Untreated	28	56	0.15	0.3	0.05	0.1	0.25[m]	0.5[m]	0.1[m]	0.2[m]
	Scrubber or ESP	0.25	0.5	-	-	0.05	0.1	0.25[m]	0.5[m]	0.1[m]	0.2[m]
Turpentine condenser	Untreated	-	-	-	-	-	-	0.005	.01	0.25	0.5
Miscellaneous[n]	Untreated	-	-	-	-	-	-	-	-	0.25	0.5

[a] References 8-10. Factors expressed in unit weight of air dried unbleached pulp (ADP). RSH = Methyl mercaptan. RSR = Dimethyl sulfide. RSSR = Dimethyl disulfide. ESP = Electrostatic precipitator. Dash = No data.

[b] If noncondensible gases from these sources are vented to lime kiln, recovery furnace or equivalent, the reduced sulfur compounds are destroyed.

[c] Apply with system using condensate as washing medium. When using fresh water, emissions are 0.05 (0.1).

[d] Apply when cyclonic scrubber or cascade evaporator is used for direct contact evaporation, with no further controls.

[e] Usually reduced by 50% with black liquor oxidation and can be cut 95 - 99% when oxidation is complete and recovery furnace is operated optimally.

[f] Apply when venturi scrubber is used for direct contact evaporation, with no further controls.

[g] Use 7.5 (15) when auxiliary scrubber follows venturi scrubber, and 1.5 (3) when it follows ESP.

[h] Apply when recovery furnace is operated optimally to control total reduced sulfur (TRS) compounds.

[j] Usually reduced to 0.01 g/kg (0.02 lb/ton) ADP when water low in sulfides is used in smelt dissolving tank and associated scrubber.

[m] Usually reduced to 0.015 g/kg (0.03 lb/ton) ADP with efficient mud washing, optimal kiln operation and added caustic in scrubbing water. With only efficient mud washing and optimal process control, TRS compounds reduced to 0.04 g/kg (0.08 lb/ton) ADP.

[n] Includes knotter vents, brownstock seal tanks, etc. When black liquor oxidation is included, emissions are 0.3 (0.6).

TABLE 10.1-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITH A DIRECT CONTACT EVAPORATOR AND AN ESP[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	95.0	-	86	-
10	93.5	-	84	-
6	92.2	68.2	83	0.7
2.5	83.5	53.8	75	0.5
1.25	56.5	40.5	51	0.4
1.00	45.3	34.2	41	0.3
0.625	26.5	22.2	24	0.2
Total	100	100	90	1.0

[a] Reference 7. Dash = no data.

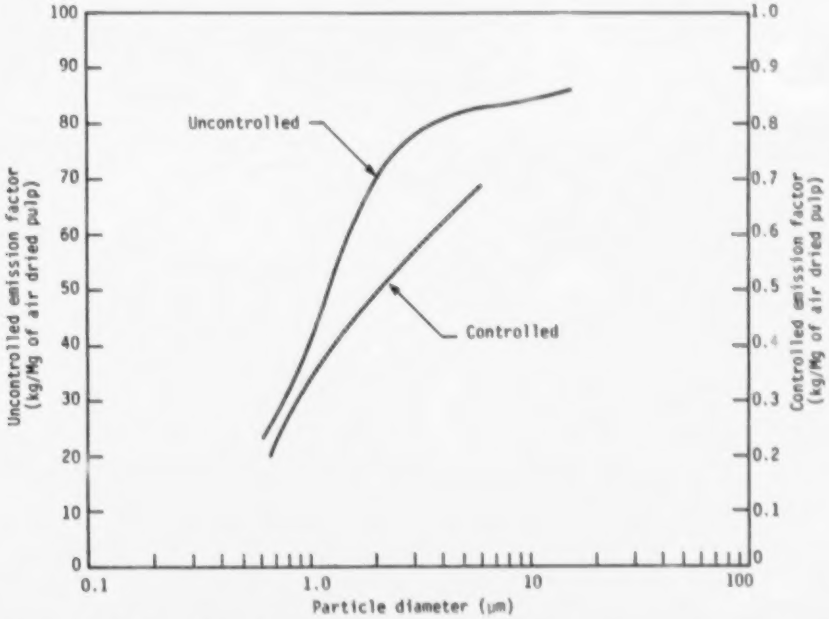

Figure 10.1-2. Cumulative particle size distribution and size specific emission factors for recovery boiler with direct contact evaporator and ESP.

TABLE 10.1-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITHOUT A DIRECT CONTACT EVAPORATOR BUT WITH AN ESP[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	-	78.8	-	0.8
10	-	74.8	-	0.7
6	-	71.9	-	0.7
2.5	78.0	67.3	90	0.6
1.25	40.0	51.3	46	0.5
1.00	30.0	42.4	35	0.4
0.625	17.0	29.6	20	0.3
Total	100	100	115	1.0

[a] Reference 7. Dash = no da

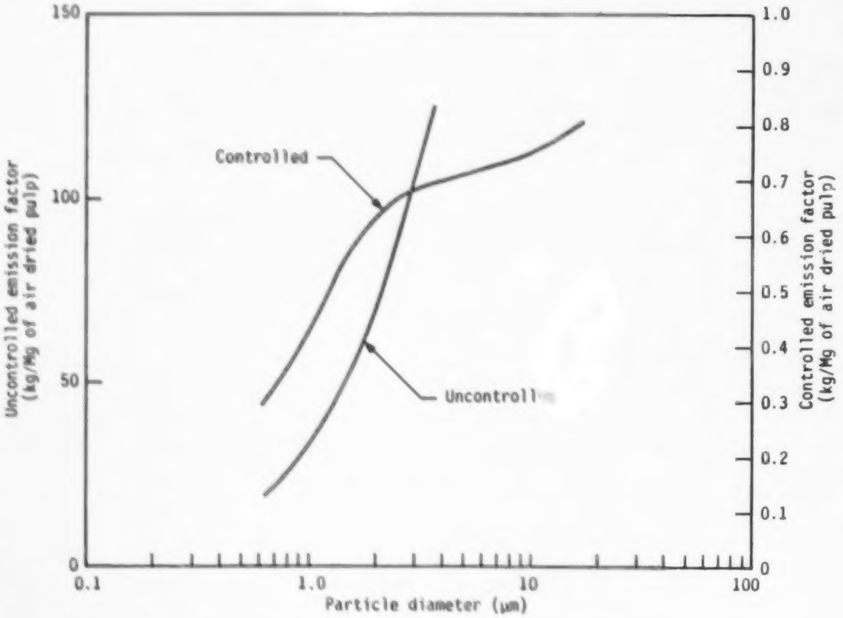

Figure 10.1-3. Cumulative particle size distribution and size specific emission factors for recovery boiler without direct contact evaporator but with ESP.

TABLE 10.1-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH A VENTURI SCRUBBER[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	27.7	98.9	7.8	0.24
10	16.8	98.3	4.7	0.24
6	13.4	98.2	3.8	0.24
2.5	10.5	96.0	2.9	0.24
1.25	8.2	85.0	2.3	0.21
1.00	7.1	78.9	2.0	0.20
0.625	3.9	54.3	1.1	0.14
Total	100	100	28.0	0.25

[a] Reference 7.

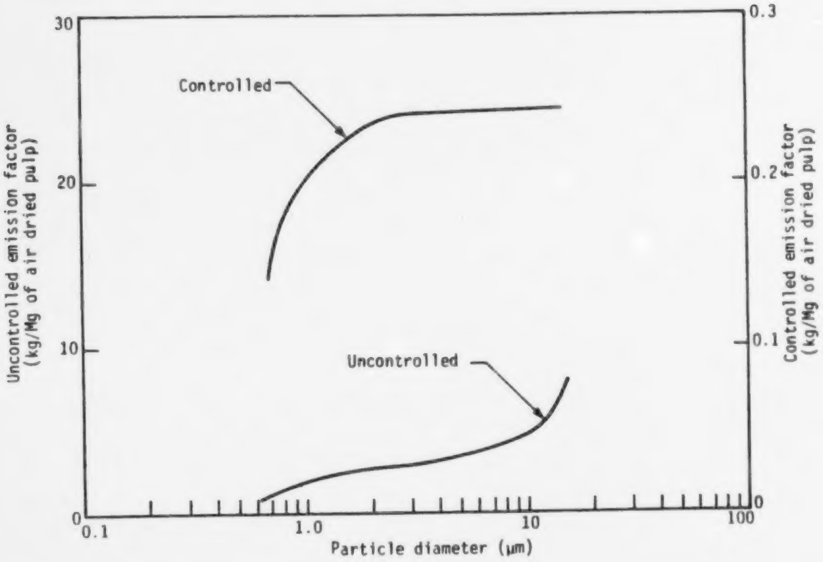

Figure 10.1-4. Cumulative particle size distribution and size specific emission factors for lime kiln with venturi scrubber.

TABLE 10.1-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH AN ESP[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	27.7	91.2	7.8	0.23
10	16.8	88.5	4.7	0.22
6	13.4	86.5	3.8	0.22
2.5	10.5	83.0	2.9	0.21
1.25	8.2	70.2	2.3	0.18
1.00	7.1	62.9	2.0	0.16
0.625	3.9	46.9	1.1	0.12
Total	100	100	28.0	0.25

[a] Reference 7.

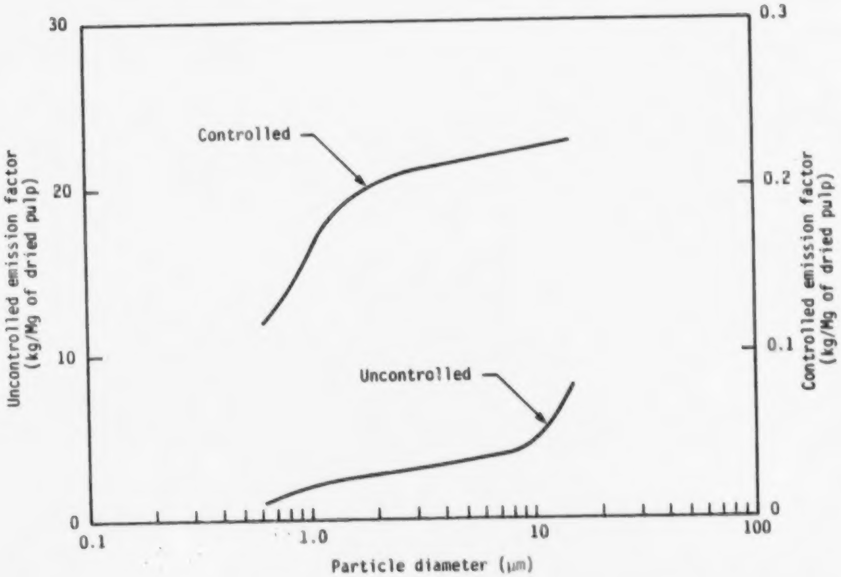

Figure 10.1-5. Cumulative particle size distribution and size specific emission factors for lime kiln with ESP.

TABLE 10.1-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK WITH A PACKED TOWER[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	90.0	95.3	3.2	0.48
10	88.5	95.3	3.1	0.48
6	87.0	94.3	3.0	0.47
2.5	73.0	85.2	2.6	0.43
1.25	47.5	63.8	1.7	0.32
1.00	40.0	54.2	1.4	0.27
0.625	25.5	34.2	0.9	0.17
Total	100	100	3.5	0.50

[a] Reference 7.

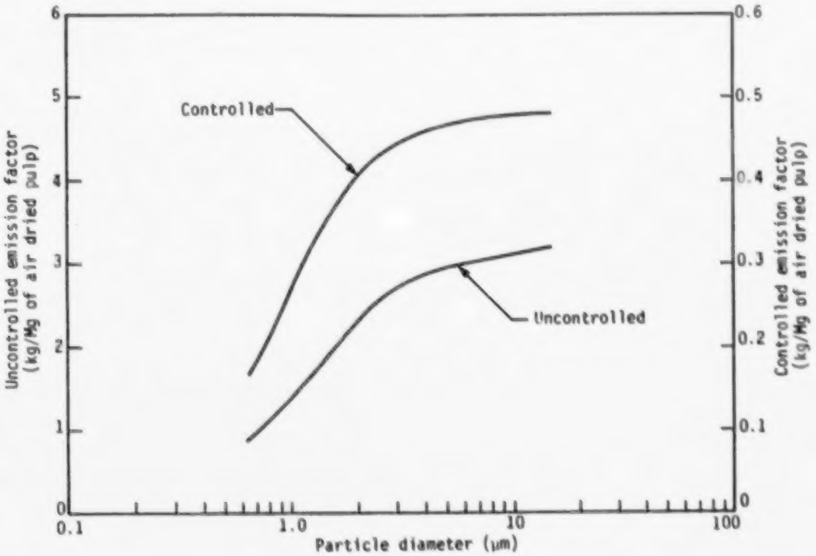

Figure 10.1-6. Cumulative particle size distribution and size specific emission factors for smelt dissolving tank with packed tower.

TABLE 10.1-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK WITH A VENTURI SCRUBBER[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	90.0	89.9	3.2	0.09
10	88.5	89.5	3.1	0.09
6	87.0	88.4	3.0	0.09
2.5	73.0	81.3	2.6	0.08
1.25	47.5	63.5	1.7	0.06
1.00	54.0	54.7	1.4	0.06
0.625	25.5	38.7	0.9	0.04
Total	100	100	3.5	0.09

[a] Reference 7.

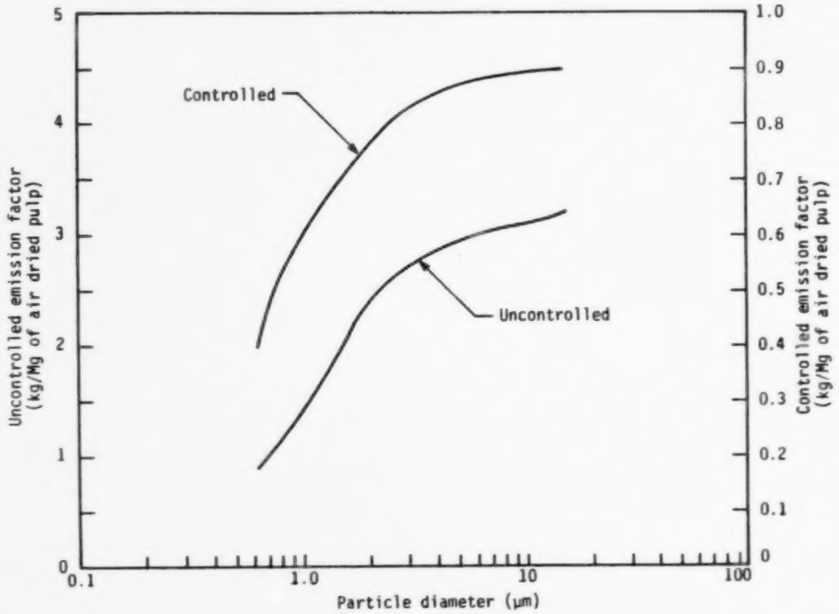

Figure 10.1-7. Cumulative particle size distribution and size specific emission factors for smelt dissolving tank with venturi scrubber.

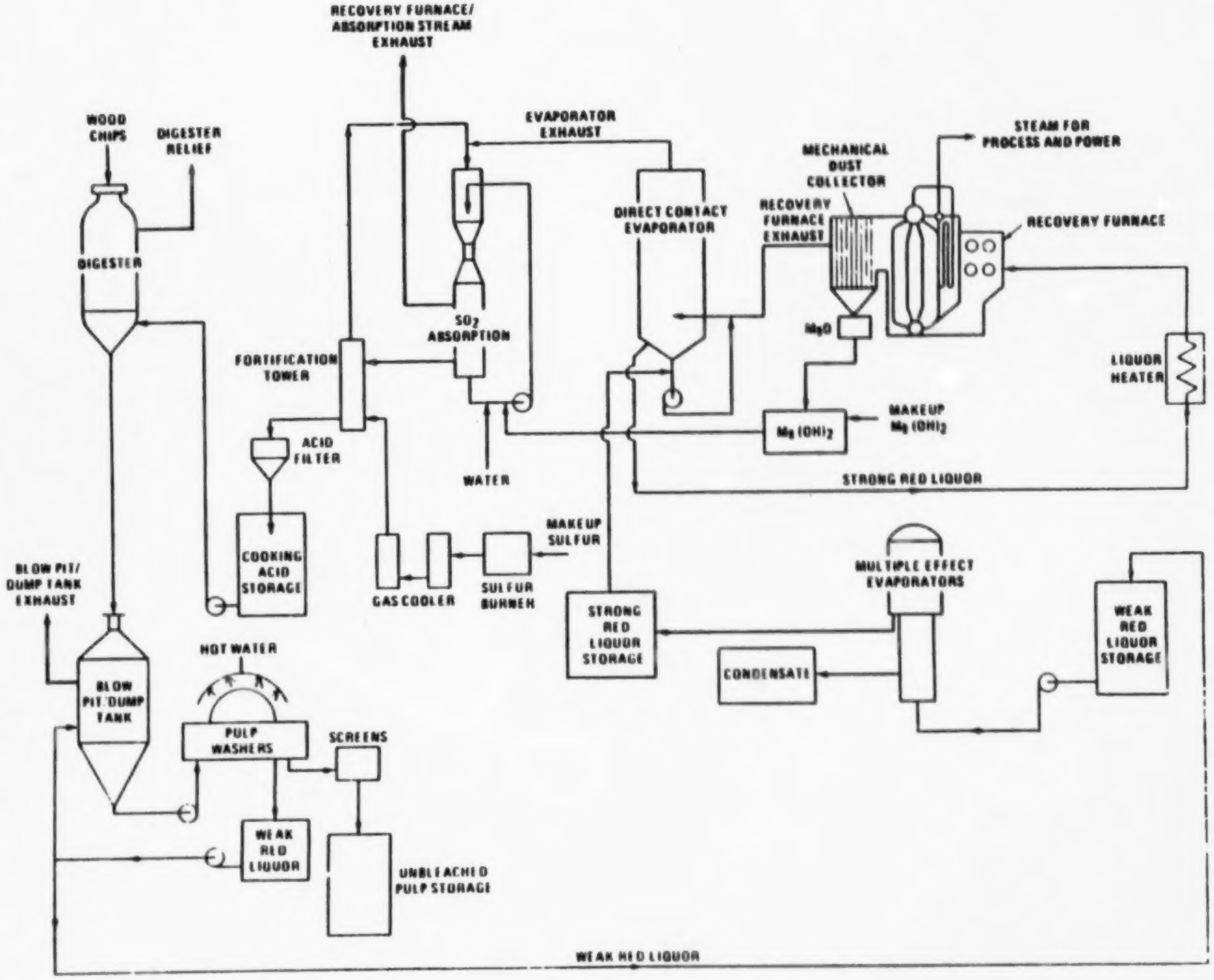
RECOVERY FURNACE/ ABSORPTION STREAM EXHAUST
WOOD CHIPS
DIGESTER RELIEF
EVAPORATOR EXHAUST
STEAM FOR PROCESS AND POWER
MECHANICAL DUST COLLECTOR
DIRECT CONTACT EVAPORATOR
RECOVERY FURNACE EXHAUST
RECOVERY FURNACE
DIGESTER
SO_2 ABSORPTION
FORTIFICATION TOWER
MgO
LIQUOR HEATER
MAKEUP $Mg(OH)_2$
$Mg(OH)_2$
ACID FILTER
WATER
STRONG RED LIQUOR
MAKEUP SULFUR
COOKING ACID STORAGE
GAS COOLER
SULFUR BURNER
MULTIPLE EFFECT EVAPORATORS
BLOW PIT/ DUMP TANK EXHAUST
STRONG RED LIQUOR STORAGE
WEAK RED LIQUOR STORAGE
HOT WATER
CONDENSATE
BLOW PIT/DUMP TANK
PULP WASHERS
SCREENS
WEAK RED LIQUOR
UNBLEACHED PULP STORAGE
WEAK RED LIQUOR

Figure 10.1-8. Simplified process flow diagram of magnesium-base process employing chemical and heat recovery.

incinerated, or sent to a plant for recovery of heat and chemicals. The pulp is then washed and processed through screens and centrifuges to remove knots, bundles of fibers and other material. It subsequently may be bleached, pressed and dried in papermaking operations.

Because of the variety of cooking liquor bases used, numerous schemes have evolved for heat and/or chemical recovery. In calcium base systems, found mostly in older mills, chemical recovery is not practical, and the spent liquor is usually discharged or incinerated. In ammonium base operations, heat can be recovered by combusting the spent liquor, but the ammonium base is thereby consumed. In sodium or magnesium base operations, the heat, sulfur and base all may be feasibly recovered.

If recovery is practiced, the spent (weak) red liquor (which contains more than half of the raw materials as dissolved organic solids) is concentrated in a multiple effect evaporator and a direct contact evaporator to 55 to 60 percent solids. This strong liquor is sprayed into a furnace and burned, producing steam to operate the digesters, evaporators, etc. and to meet other power requirements.

When magnesium base liquor is burned, a flue gas is produced from which magnesium oxide is recovered in a multiple cyclone as fine white power. The magnesium oxide is then water slaked and is used as circulating liquor in a series of venturi scrubbers, which are designed to absorb sulfur dioxide from the flue gas and to form a bisulfite solution for use in the cook cycle. When sodium base liquor is burned, the inorganic compounds are recovered as a molten smelt containing sodium sulfide and sodium carbonate. This smelt may be processed further and used to absorb sulfur dioxide from the flue gas and sulfur burner. In some sodium base mills, however, the smelt may be sold to a nearby kraft mill as raw material for producing green liquor.

If liquor recovery is not practiced, an acid plant is necessary of sufficient capacity to fulfill the mill's total sulfite requirement. Normally, sulfur is burned in a rotary or spray burner. The gas produced is then cooled by heat exhangers and a water spray and is then absorbed in a variety of different scrubbers containing either limestone or a solution of the base chemical. Where recovery is practiced, fortification is accomplished similarly, although a much smaller amount of sulfur dioxide must be produced to make up for that lost in the process.

Emissions And Controls[11] - Sulfur dioxide is generally considered the major pollutant of concern from sulfite pulp mills. The characteristic "kraft" odor is not emitted because volatile reduced sulfur compounds are not products of the lignin/bisulfite reaction.

A major SO_2 source is the digester and blow pit (dump tank) system. Sulfur dioxide is present in the intermittent digester relief gases, as well as in the gases given off at the end of the cook when the digester contents are discharged into the blow pit. The quantity of sulfur dioxide evolved and emitted to the atmosphere in these gas streams depends on the pH of the cooking liquor, the pressure at which the digester contents are discharged, and the effectiveness of the absorption systems employed for SO_2 recovery. Scrubbers can be installed that reduce SO_2 from this source by as much as 99 percent.

Another source of sulfur dioxide emissions is the recovery system. Since magnesium, sodium, and ammonium base recovery systems all use absorption systems to recover SO_2 generated in recovery furnaces, acid fortification towers, multiple effect evaporators, etc., the magnitude of SO_2 emissions depends on the desired efficiency of these systems. Generally, such absorption systems recover better than 95 percent of the sulfur so it can be reused.

The various pulp washing, screening, and cleaning operations are also potential sources of SO_2. These operations are numerous and may account for a significant fraction of a mill's SO_2 emissions if not controlled.

The only significant particulate source in the pulping and recovery process is the absorption system handling the recovery furnace exhaust. Ammonium base systems generate less particulate than do magnesium or sodium base systems. The combustion productions are mostly nitrogen, water vapor and sulfur dioxide.

Auxiliary power boilers also produce emissions in the sulfite pulp mill, and emission factors for these boilers are presented in Chapter 1.

Table 10.1-8 contains emission factors for the various sulfite pulping operations.

10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping

Process Description[9, 12-14] - In this method, wood chips are cooked in a neutral solution of sodium sulfite and sodium carbonate. Sulfite ions react with the lignin in wood, and the sodium bicarbonate acts as a buffer to maintain a neutral solution. The major difference between all semichemical techniques and those of kraft and acid sulfite processes is that only a portion of the lignin is removed during the cook, after which the pulp is further reduced by mechanical disintegration. This method achieves yields as high as 60 to 80 percent, as opposed to 50 to 55 percent for other chemical processes.

The NSSC process varies from mill to mill. Some mills dispose of their spent liquor, some mills recover the cooking chemicals, and some, when operated in conjunction with kraft mills, mix their spent liquor with the kraft liquor as a source of makeup chemcials. When recovery is practiced, the involved steps parallel those of the sulfite process.

Emissions And Controls[9,12-14] - Particulate emissions are a potential problem only when recovery systems are involved. Mills that do practice recovery but are not operated in conjunction with kraft operations often utilize fluidized bed reactors to burn their spent liquor. Because the flue gas contains sodium sulfate and sodium carbonate dust, efficient particulate collection may be included for chemical recovery.

A potential gaseous pollutant is sulfur dioxide. Absorbing towers, digester/blower tank system, and recovery furnace are the main sources of SO_2, with amounts emitted dependent upon the capability of the scrubbing devices installed for control and recovery.

Hydrogen sulfide can also be emitted from NSSC mills which use kraft type recovery furnaces. The main potential source is the absorbing tower, where a

TABLE 10.1-8. EMISSION FACTORS FOR SULFITE PULPING[a]

Source	Base	Control	Emission factor[b]				Emission Factor Rating
			Particulate		Sulfur dioxide		
			kg/ADUMg	lb/ADUT	kg/ADUMg	lb/ADUT	
Digester/blow pit or dump tank[c]	All	None	Neg	Neg	5 to 35	10 to 70	C
	MgO	Process change[d]	Neg	Neg	1 to 3	2 to 6	C
	MgO	Scrubber	Neg	Neg	0.5	1	B
	MgO	Process change and scrubber	Neg	Neg	0.1	0.2	B
	MgO	All exhaust vented through recovery system	Neg	Neg	0	0	A
	NH_3	Process change	Neg	Neg	12.5	25	D
	NH_3	Process change and scrubber	Neg	Neg	0.2	0.4	B
	Na	Process change and scrubber	Neg	Neg	1	2	C
	Ca	Unknown	Neg	Neg	33.5	67	C
Recovery system[e]	MgO	Multicyclone and venturi scrubbers	1	2	4.5	9	A
	NH_3	Ammonia absorption and mist eliminator	0.35	0.7	3.5	7	B
	Na	Sodium carbonate scrubber	2	4	1	2	C
Acid plant[f]	NH_3	Scrubber	Neg	Neg	0.2	0.3	C
	Na	Unknown[g]	Neg	Neg	0.1	0.2	D
	Ca	Jenssen scrubber	Neg	Neg	4	8	C
Other[h]	All	None	Neg	Neg	6	12	D

[a] Reference 11. All factors represent long term average emissions. ADUMg = Air dried unbleached megagram. ADUT = Air dried unbleached ton. Neg = negligible.

[b] Expressed as kg (lb) of pollutant/air dried unbleached ton (mg) of pulp.

[c] Factors represent emissions after cook is completed and when digester contents are discharged into blow pit or dump tank. Some relief gases are vented from digester during cook cycle, but these are usually transferred to pressure accumulators and SO_2 therein reabsorbed for use in cooking liquor. In some mills, actual emissions will be intermittent and for short periods.

[d] May include such measures as raising cooking liquor pH (thereby lowering free SO_2), relieving digester pressure before contents discharge, and pumping out digester contents instead of blowing out.

[e] Recovery system at most mills is closed and includes recovery furnace, direct contact evaporator, multiple effect evaporator, acid fortification tower, and SO_2 absorption scrubbers. Generally only one emission point for entire system. Factors include high SO_2 emissions during periodic purging of recovery systems.

[f] Necessary in mills with insufficient or nonexistent recovery systems.

[g] Control is practiced, but type of system is unknown.

[h] Includes miscellaneous pulping operations such as knotters, washers, screens, etc.

significant quantity of hydrogen sulfite is liberated as the cooking liquor is made. Other possible sources, depending on the operating conditions, include the recovery furnace, and in mills where some green liquor is used in the cooking process, the digester/blow tank system. Where green liquor is used, it is also possible that significant quantities of mercaptans will be produced. Hydrogen sulfide emissions can be eliminated if burned to sulfur dioxide before the absorbing system.

Because the NSSC process differs greatly from mill to mill, and because of the scarcity of adequate data, no emission factors are presented for this process.

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13. M. Benjamin, et al., "A General Description of Commercial Wood Pulping and Bleaching Processes", Journal of the Air Pollution Control Association, 19(3):155-161, March 1969.

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APPENDIX A

LIST OF CONTACTS

LIST OF CONTACTS

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APPENDIX B

LIST OF KRAFT PULP MILLS

LIST OF KRAFT PULP MILLS

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
ALABAMA			
Allied Paper, Inc. (Subsidiary of SCM)	490	Jackson	Printing and writing papers
American Can Company	900	Butler	Tissue; toweling; box, paper, and package board
Champion International	500	Courtland	Uncoated printing, writing, business, and converting papers
Container Corporation of America (Subsidiary of MARCOR)	850	Brewton	Paperboard, food-liquid board, kraft paper, linerboard
Georgia Kraft Corporation (50 percent owned by Inland Container; 50 percent owned by Mead Corporation)	975	Mahrt	Linerboard, kraft board
Gulf States Paper Corporation	400	Demopolis	Paperboard
Gulf States Paper Corporation	475	Tuscaloosa	Kraft bag and wrapping
Hammermill Paper Company	500	Selma	None
International Paper Company	1,350	Mobile	Paper
Kimberly-Clark Corportation	585	Coosa Pines	Newsprint
MacMillan Bloedel Ltd.	925	Pine Hill	Paperboard
Scott Paper Company	1,400	Mobile	Tissue and other paper grades
Union Camp Corporation	930	Montgomery	Paperboard
ARIZONA			
Southwest Forest Industries	600	Snowflake	Newsprint, linerboard
ARKANSAS			
Georgia-Pacific Corporation	1,500	Crossett	Kraft paper, tissue, and paperboard
Great Northern Nekoosa Corporation	400	Ashdown	Business communications papers
Green Bay Packing, Inc.	650	Morrilton	Paperboard
International Paper Company	750	Camden	Paper
International Paper Company	1,900	Pine Bluff	Paper and board
Weyerhaeuser Company	230	Pine Bluff	Paper and board
CALIFORNIA			
Crown Simpson Company (jointly owned by Crown Zellerbach and Simpson Lee Paper Company)	600	Fairhaven	None
Fibreboard Corporation	450	Antioch	Paperboard
Louisiana-Pacific Corporation	700	Samoa	None
Simpson Lee Paper Company	160	Anderson	Coated printing paper, machine finish grades
FLORIDA			
Alton Box Board Company	650	Jacksonville	Board
Container Corporation of America (Subsidiary of MARCOR)	1,400	Fernandina Beach	Paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Continued)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
FLORIDA (Continued)			
Hudson Pulp and Paper Corporation	950	Palatka	Tissue and bag papers
International Paper Company	1,500	Panama City	Containerboard
Proctor & Gamble Company	900	Foley	None
St. Joe Paper Company	1,300	Port St. Joe	Paperboard
St. Regis Paper Company	1,510	Jacksonville	Kraft paper and board
St. Regis Paper Company	1,050	Pensacola	Paper and board
GEORGIA			
Continentil Can Company	800	Augusta	Paperboard
Continentil Can Company	600	Port Wentworth	Paperboard
Brunswick Pulp and Paper Company (50 percent owned by Mead Corporation, 50 percent owned by Scott Paper)	1,550	Brunswick	Paperboard
Georgia Kraft Corporation (50 percent owned by Inland Container Corporation, 50 percent owned by Mead Corporation)	1,550	Krannert (Rome)	Paperboard (containerboard)
Georgia Kraft Corporation (50 percent owned by Inland Container Corporation, 50 percent owned by Mead Corporation)	900	Macon	Paperboard (containerboard)
Gilman Paper Company	1,100	St. Marys	Paper and board
Great Northern Nekoosa Corporation	1,780	Cedar Springs	Paper and corrugating medium
Interstate Paper Corporation	550	Riceboro	Paperboard and kraft board
ITT Rayonier, Inc.	1,250	Jesup	None
Owens-Illinois, Inc.	875	Valdosta	Board
Union Camp Corporation	2,550	Savannah	Paperboard, unbleached paper, and semichemical medium
IDAHO			
Potlatch Corporation	950	Lewiston	Paperboard and tissue
KENTUCKY			
Western Kraft (division of Willamette Industries, Inc.)	320	Hawesville	None
Westvaco	600	Wickliffe	Fine papers
LOUISIANA			
Boise Cascade Corporation	1,250	DeRidder	Newsprint and linerboard
Boise Cascade Corporation	325	Elizabeth	Bag, bag lining, converting, envelopes, wrapping
Continental Can Company	1,400	Hodge	Coarse paper and paperboard

Source: *Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.*

LIST OF KRAFT PULP MILLS (Continued)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
LOUISIANA (Continued)			
Crown Zellerbach	1,350	Bogalusa	Paperboard, Kraft wrapping and bag
Crown Zellerbach	500	St. Francisville	Coated papers, Kraft paper and board
Georgia-Pacific Corporation	1,600	Port Hudson	None
International Paper Company	1,100	Bastrop	Kraft paper and board
International Paper Company	1,650	Springhill	Paper and board
Western Kraft	450	Campti	Paper and board
Olin Kraft, Inc.	1,150	West Monroe	Kraft paper and board, and corrugating medium
Pineville Kraft Corporation	880	Pineville	Kraft liner board
MAINE			
Diamond International Corporation	425	Old Town	Tissue
Georgia-Pacific Corporation	1,170	Woodland	Printing papers and newsprint
International Paper Company	1,150	Jay (Androscoggin)	Bond, carbonizing, and coated printing papers
Lincoln Pulp and Paper Company, Inc. Division of Premoid	320	Lincoln	Fine paper and tissue
Oxford Paper (Division of Ethyl Corporation)	585	Rumford	Fine printing and publishing papers
S. D. Warren Company, Division of Scott Paper Company	300	Westbrook	Specialty and other papers
MARYLAND			
Westvaco Corporation	665	Luke	Fine papers
MICHIGAN			
Mead Corporation	600	Escanaba	Coated printing papers
Scott Paper Company	225	Muskegon	Fine papers
MINNESOTA			
Boise Cascade Corporation	465	International Falls	Printing, publishing and white papers; insulation board
Potlatch Corporation	400	Cloquet	Printing and business paper
MISSISSIPPI			
International Paper Company	715	Moss Point	Paper
International Paper Company	1,000	Natchez	None
International Paper Company	1,200	Vicksburg	Containerboard
St. Regis Paper Company	1,792	Monticello	Linerboard and paper
MONTANA			
Hoerner Waldorf Corporation	1,200	Missoula	Paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Continued)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
NEW HAMPSHIRE			
Brown Company	700	Berlin-Gorham	Paper, printing, industrial tissue and towel, corrugating
NEW YORK			
International Paper Company	590	Ticonderoga	Book and business grades
NORTH CAROLINA			
Champion International	1,360	Canton	Uncoated printing, writing, and converting papers, bleached paperboard for milk and folding cartons
Federal Paper Board Company	1,200	Riegelwood	Paperboard
Hoerner Waldorf Corporation	950	Roanoke Rapids	Paperboard
Weyerhaeuser Company	640	New Bern	None
Weyerhaeuser Company	1,500	Plymouth	Paperboard and fine papers
OHIO			
Mead Corporation	540	Chillocothe	Fine papers
OKLAHOMA			
Weyerhaeuser Company	1,600	Valliant	Paperboard
OREGON			
American Can Company	340	Halsey	Tissue
Boise Cascade Corporation	1,050	St. Helens	Specialty and fine papers
Crown Zellerbach	916	Clatskanie	Newsprint, tissue, industrial
Georgia-Pacific	1,250	Toledo	Kraft paper, paperboard
International Paper Company	600	Gardiner	Paperboard
Western Kraft (Willamette Industries, Inc.)	600	Albany	Kraft papers, corrugating medium
Weyerhaeuser Company	1,150	Springfield	Paperboard
PENNSYLVANIA			
Appleton Papers, Inc. (Division of National Cash Register)	180	Roaring Springs	Fine papers
P. H. Glatfelter Co.	500	Sprint Grove	Printing and writing papers
Penntech Papers, Inc.	180	Johnsonburg	Fine, printing, publishing, and business paper
SOUTH CAROLINA			
Bowater, Inc.	1,000	Catawba	Book papers
International Paper Company	1,830	Georgetown	Board and corrugating medium
South Carolina Ind., Inc. (79 percent owned by Stone Container Corporation)	675	Florence	Paperboard
Westvaco Corporation	1,989	Charleston	Paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Concluded)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
TENNESSEE			
Bowater, Inc.	500	Calhoun	Newsprint
Packaging Corporation of America (Subsidiary of Tenneco)	775	Counce	Paperboard
TEXAS			
Champion International	820	Pasadena	Uncoated and coated printing, writing, and converting papers
International Paper Company	650	Texarkana	Paperboard
Owens-Illinois, Inc.	900	Orange	Board
Southland Paper Mills, Inc.	500	Houston	Newsprint and kraft paper
Southland Paper Mills, Inc.	400	Lufkin	Newsprint
Temple-Eastex, Inc. (Subsidiary of Time, Inc.)	1,300	Evadale	Paper and paperboard
VIRGINIA			
Chesapeake Corporation of Virginia	1,150	West Point	Coarse paper and paperboard
Continental Can Company	900	Hopewell	Paperboard
Union Camp Corporation	1,500	Franklin	Paperboard and fine, industrial, and coarse papers
Westvaco Corporation	1,000	Covington	Paperboard and corrugating medium
WASHINGTON			
Boise Cascade Corporation	700	Wallula	Linerboard and corrugating medium
Crown Zellerbach	730	Camas	Tissues; industrial, and fine papers
Crown Zellerbach	420	Port Townsend	Paper and paperboard
Longview Fibre Company	1,900	Longview	Paperboard and kraft paper
St. Regis Paper Company	1,029	Tacoma	Linerboard; natural and white paper
Weyerhaeuser Company	375	Everett	None
Weyerhaeuser Company	700	Longview	Paperboard and bristol papers
WISCONSIN			
Consolidated Papers, Inc.	395	Wisconsin Rapids	None
Great Northern Nekoosa Corporation	330	Nekoosa	Business communications papers
Hammermill Paper Company	356	Kaukauna	Packaging and special industrial papers
Mosinee Paper Corporation	175	Mosinee	Paper and paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

APPENDIX C

REVISED AP-42 SECTION DOCUMENTATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

19 MAY 1986

MEMORANDUM

SUBJECT: Documentation for Emission Factor Development for Kraft Pulp Mills

FROM: James A. Eddinger, Environmental Engineer
Industrial Studies Branch, ESED (MD-13) James A. Eddinger

TO: Frank M. Noonan, Environmental Engineer
Source Analysis Section, AMTB (MD-14)

This memo presents the documentation for the revised AP-42 emission factors for kraft pulp mills. The emission factors for controlled sources were based mainly on data gathered during the review of the new source performance standards (NSPS) for the kraft pulp industry. The emission factors for uncontrolled sources were principally developed from data presented in the document entitled Atmospheric Emissions From The Pulp And Paper Manufacturing Industry, (Reference 1) published jointly by EPA and the National Council of the Paper Industry for Air and Steam Improvement (NCASI). A complete listing of references are attached.

The following sections document the data, procedures and calculations used in deriving the revised emission factors for each source:

1. Digester System

Data on uncontrolled total reduced sulfur (TRS) emissions from digester relief and blow gases are presented in Reference 1, Table 3 (attached). The table presents data for both relief and blow gases on only 4 digester systems (No. 1, 2, 4, and 5). Data for the No. 5 system were not used because the data were reported to be probably incorrect due to the fact that the flow rate and TRS emission measurements were taken at different locations.[1] Average TRS emissions were calculated from the remaining three systems (No. 1, 2, and 4). TRS emissions for relief gases and blow gases averaged 0.5 and 0.7 pound per ton of air dried pulp (lb/TADP), respectively. Therefore, the average uncontrolled TRS emission rate for the entire digester system is 1.2 lb/TADP. The average hydrogen sulfide (H_2S) concentrations for the relief and blow gases were calculated to be 47 and 97 parts per million respectively. Using the average total TRS concentrations calculated, the H_2S content of the relief and blow gases is 0.5 and 4 percent respectively. Therefore, the H_2S portion was calculated to be 0.03 lb/TADP for the total system.

The emission factors calculated for the uncontrolled emissions from a digester system are 0.03 lb/TADP for H_2S and 1.2 lb/TADP for the remaining three TRS compounds (methyl mercaptan, dimethyl sulfide, and dimethyl disulfide). These vent gases are normally controlled by incineration in a lime kiln where the TRS compounds are destroyed. The NSPS for digester system is 5 ppm or 0.01 lb/TADP.[2]

2. Brown Stock Washers

Data for TRS emissions from brown stock washers are presented in Reference 1, Table 31 (attached) for 17 systems. The average TRS emission rates calculated are 0.1 lb/TADP for the 14 systems using fresh water and 0.4 lb/TADP for the 5 systems using condensate. The TRS emissions are dominantly dimethyl sulfide [$(CH_3)_2S$] and dimethyl disulfide [$(CH_3)_2S_2$][1]. These uncontrolled emission factors are for vacuum drum type washing systems. TRS emissions from the newer diffusion washers are about 0.001 lb/TADP.[3] The NSPS for brown stock washer systems is 5 ppm which is based on incineration of the vent gases in a recovery furnace or equivalent.

3. Multiple Effect Evaporators

Data on uncontrolled TRS emissions from multiple effect evaporators are presented in Reference 1, Table 7 (attached) for 8 systems. The average uncontrolled TRS emission rate was calculated to be 1.2 lb/TADP, with H_2S comprising 93 percent or 1.1 lb/TADP. These vent gases are normally controlled by incineration in a lime kiln where the TRS compounds are destroyed. The NSPS for multiple effect evaporators is 5 ppm.

4. Recovery Furnaces

Data on uncontrolled emissions of particulate matter (PM) from recovery furnaces with direct contact evaporators are presented in Reference 1, Table A-1 (attached) for 62 recovery furnaces. The average uncontrolled PM emission rate was calculated to be 178 lb/TADP.

Uncontrolled PM emissions from recovery furnaces without direct contact evaporators were reported by 3 mills.[4-6] The average uncontrolled PM emission rate for these 3 units was calculated to be 230 lb/TADP.

Reference 1, Table 12 (attached) presented data on 10 recovery furnaces controlled by venturi scrubbers. The calculated average PM emission rate for these units is 48 lb/TADP.

Data on PM emissions from recovery furnaces controlled by electrostatic precipitators (ESP) were obtained for 7 units. All but two are subject to the NSPS which is 0.044 grain per dry standard cubic foot (about 0.2 lb/TADP). Since these test reports generally reported results in terms of gr/dscf or lb/hr, the actual PM emission rates in terms of lb/TADP had to calculated from available data. The following sections discuss how the lb/TADP emission rate was calculated for each of the 7 units.

A. The average PM emission rate reported for 3 test runs was 68.5 lb/hr.[7] The test report listed an average black liquor solids (BLS) feed rate of 73.2 tons/hr. Using the value of 3540 lbs BLS/TADP[8], an average pulp production rate was calculated to be 41.4 TADP/hr. Therefore, an average PM emission rate of 1.6 lb/TADP was calculated for this unit. This unit is subject to the NSPS.

B. Two test runs were performed at this unit. The average PM rate was 0.033grains/SDCF[9]. The average gas flow rate was 156,280 sdcfm. The average PM rate during the tests was 3,110,400 lb BLS/day. Using the value of 3223 lbs BLS/TADP,[9] an average PM emission rate of 1.1 lb/TADP was calculated. This unit is subject to the NSPS.

C. The average PM emission rate reported for 3 runs was 54.1 lb/hr.[10] The average pulp production rate during the tests was 27.3 tons/hr. Using these values, an average PM emission rate of 2.0 lb/TADP was calculated. This unit is subject to the NSPS.

D. Three test runs were performed at this unit. The average PM emission rate reported is 0.14 lb/TADP.[11] This unit is subject to the NSPS.

E. This unit has two stacks. Data were reported for two runs on each stack.[6] The average PM rates reported were 6.4 and 16.5 lb/hr from the two stacks. The test report also presented values for black liquor (BL) flow rate, BL solids, and BLS density. Using these values, an average BLS feed rate could be calculated by the following equation: BL feed rate (lb/hr) = BL flow rate (gpm)x BL density (lb/gal)x BLS(%). Using the value of 2975 lb BLS/TADP[6], the average PM emission rate was calculated to be 0.6 lb/TADP. This unit is subject to the NSPS.

F. Three test runs were performed by EPA on this unit as part of the NSPS development program. The unit had an average PM emission rate of 88 lb/hr and an average pulp production rate of 334.5 tons/day.[12] The average PM emission rate was calculated to be 6.3 lb/TADP.

G. This unit was also tested by EPA during the NSPS development program. Six test runs were performed. The average PM emission rate was 1.3 lb/TADP.[13]

The calculated average PM emission rate for these 7 recovery furnaces controlled by ESP's is 2 lb/TADP.

Sulfur dioxide (SO_2) emission data were available from Reference 1, Table 14 (attached) for 23 recovery furnaces. These units were uncontrolled for TRS emissions. The SO_2 data were presented in terms of ppm. Gas flow rate, stack temperature, and pulp production values were also given for each of the 23 units. The SO_2 emission rate in terms of lb/TADP had to be calculated for each unit. The average SO_2 emission rate for the 23 units was calculated to be 7 lb/TADP. Reference 1 Table 19 (attached) presented data on SO_2 emissions from a scrubber installed after an ESP. The calculated SO_2 emissions from this scrubber was 5 lb/TADP. The SO_2 emissions were reported in ppm. The mass rate (lb/TADP) was calculated by multiplying the ratio of the SO_2 and TRS (as H_2S) concentration (40.8 ppm SO_2/1.26 ppm H_2S) by the ratio of their molecular weight (SO_2/H_2S) and the mass rate of TRS (lb/TADP).

A report published by the NCASI presented data on carbon monoxide (CO) emissions from 5 recovery furnaces.[14] The CO emissions averaged 10.6 lb/TADP.

The NCASI also published a report presenting data on nitrogen oxide (NO_x) emissions from 10 recovery furnaces.[15] The average NO_x emission rate was 1.8 lb/TADP.

Uncontrolled TRS emissions were presented in Reference 1, Table 14 (attached) for 32 units. The average TRS emission rate was calculated to be 15 lb/TADP with H_2S comprising 81 percent or 12 lb/TADP.

During the NSPS review for kraft pulp mills, TRS monitoring data were obtained from recovery furnaces controlled for TRS emissions. However, the monitoring data are reported in terms of ppm. The data did support the achievability of the 5 ppm TRS standard.[16] Design information was available for 4 recovery furnaces which allowed calculation of TRS emissions in terms of lb/TADP. The following table lists the design data used for each unit:

Mill	Recovery furnace design information				Reference	Calculated TRS emission (lb/TADP)
	Production Rate (TADP/D)	Air Flow (acfm)	Temp (°F)	Moisture (%H_2O)		
Boise Cascade	850	396,307	433	26	17	0.14
Buckeye Cellulose/ GA	759	367,000	400	26	8	0.10
Champion	910	315,888	350	30	9	0.07
Nekoosa	1200	275,000	280	35	18	0.13

The following equation was used to calculate TRS emissions in terms of lb/TADP, based on an outlet TRS concentration of 5 ppm:

$$\text{TRS (lb/TADP)} = \text{5ppm} \times \text{acfm} \times (1-\%H_2O) \times \frac{520°\text{R}}{\text{Temp} + 460°\text{R}} \times \frac{\text{1440 min}}{\text{day}}$$

$$\times \frac{\text{lb-mole}}{\text{379SCF}} \times \frac{\text{34 lb}}{\text{lb-mole}} \times \frac{\text{day}}{\text{TADP}}$$

The average TRS emission rate calculated for the 4 units is 0.1 lb/TADP.

5. Smelt Dissolving Tank

Uncontrolled PM emission rates were presented in Reference 1, Table A (attached) for 9 smelt tanks. Data were also obtained for one additional uncontrolled smelt tank during the NSPS development.[19] The average uncontrolled PM emission rate for these 10 units was calculated to be 7 lb/TADP.

Reference 1, Table 23 (attached) presented data on PM emissions from 6 smelt tanks controlled by mesh pads. The average PM emission rate for these 6 units was calculated to be 1.0 lb/TADP.

Data on PM emissions from 5 smelt tanks controlled by scrubbers were obtained during the NSPS review. Also, data were available on 5 scrubber controlled smelt tanks tested during the NSPS development. Table A presents the reported PM emission rates. In three cases, the data were reported in terms of lb/TBLS. The conversion factors used to convert to lb/TADP are also listed in Table A. The average PM emission rate calculated for these 10 units controlled by scrubber is 0.2 lb/TADP.

TABLE A

Source	Reference	PM Emission (lb/TADP)
Crown Zellerbach	19	0.27
Boise Cascade	20	0.25[a]
Buckeye Cellulose	7	0.20[b]
Hammermill	10	0.22
Tennessee River	21	0.10
Continental Forest	6	0.07[c]
American Can	12	0.29
Champion	22	0.14
Mead	23	0.12
Weyerhaeuser	24	0.21

[a] Calculated from reported lb/TBLS value, using a conversion factor of 1.7 TBLS/TADP from Reference 5.

[b] Calculated from reported lb/TBLS value, using a conversion factor of 1.8 TBLS/TADP from Reference 8.

[c] Calculated from reported lb/TBLS value, using a conversion factor of 1.5 TBLS/TADP from Reference 6.

Data on SO_2 emissions were available from Reference 1, Table 24 (attached) for 8 smelt tanks. The average SO_2 emission rate calculated is 0.15 lb/TADP. The SO_2 emission rate reported in the Table is actually 0.08 lb/TADP as H_2S. Using the molecular weight ratio of SO_2 to H_2S, the value reported was converted to 0.15 lb/TADP as SO_2.

Uncontrolled TRS emissions were available from Reference 1, Table A-3 (attached) for 18 units. The average uncontrolled TRS emission rate was calculated to be 0.5 lb/TADP. The average H_2S and TRS concentrations were calculated to be 33 and 90 ppm, respectively. Therefore, the H_2S segment was calculated to be 37 percent or 0.2 lb/TADP.

Controlled TRS emissions were available from 3 units subject to the NSPS and 2 unit tested during the NSPS development program. Table B presents the reported data. In some cases, the data were reported in lb/TBLS. The conversion factors used to convert to lb/TADP are also given in Table B. The average TRS emission rate for these controlled units is 0.02 lb/TADP.

TABLE B

Source	PM Emission (lb/TBLS)	Conversion Factor (TBLS/TADP)	PM Emissions (lb/TADP)	References
Buckeye Cellulose	0.008	1.5	0.014	7,8
Boise Cascade	0.019	1.7	0.033	5,20
Continental Forest	0.002	1.5	0.003	6
Champion	-	-	0.016	22
Mead	-	-	0.008	23

6. Lime Kiln

Data on uncontrolled PM emissions from lime kilns in terms of lb/TADP were available for only 2 units. Reference 1, Table 29 (attached) presented data on scrubber efficiency (95.9 percent) and outlet emission rate (1.7 lb/ TADP) for one unit. These values were used to calculate an uncontrolled PM emission rate of 41.5 lb/TADP for that unit. A lime kiln tested during the NSPS development program had an uncontrolled PM emission rate of 71.3 lb/TADP.[25] The average of these two units is 56 lb/TADP.

Data on 4 lime kilns controlled by venturi scrubbers were obtained during the NSPS review. In addition, data were available for one lime kiln tested during the NSPS development program.

In only one case were emissions reported in terms of lb/TADP. Table C list the reported parameters used in calculating emission rates in terms of lb/TADP. The average PM emission rate for these 5 units controlled by venturi scrubbers is 0.5 lb/TADP.

Data on SO_2 emissions from lime kilns were available from Reference 1, Table A-5 (attached) for 12 inits. The SO_2 emissions were reported in ppm. The mass rate (lb/TADP) was calculated for each unit by the following equation:

$$SO_2\ (\text{lb/TADP}) = \text{ppm (acfm)}\ \frac{520^\circ \text{R}}{(\text{Temp}+460^\circ \text{R})} \times \frac{\text{lb-mole}}{379\ \text{SCF}} \times \frac{64\ \text{lb}}{\text{lb-mole}} \times \frac{1440\text{min}}{\text{day}} \times \frac{\text{day}}{\text{TADP}}$$

The average SO_2 emissions rate for the 12 units was then calculated to be 0.27 lb/TADP.

A report published by the NCASI presented data on CO emissions from 4 lime kilns.[14] The CO emission rates for these 4 units averaged 0.07 lb/TADP.

The NCASI also pubished a report presenting data on NO_x emissions from 6 lime kilns.[28] The average NO_x emission rate is 1.2 lb/TADP.

Uncontrolled TRS emissions were presented in Reference 1, Table 28 (attached). The average H_2S emission rate is 0.5 lb/TADP for 24 units. The average non-H_2S TRS emission rate is 0.15 lb/TADP for 14 units, which was calculated by summing the average emission rate reported in Table 28 for the other 3 TRS compounds.

TABLE C

Source	Report PM Emission Rate (lb/hr)	Pulp Production Rate (TADP/hr)	Calculated PM Rate (lb/TADP)	References
Hammermill	4.4	18.4[a]	0.24	10,27
Willamette	5.8	25.5[b]	0.23	16,26
Champion	9.7[c]	36.1[d]	0.27	9
Hammermill	11.5	23.3	0.50	10
Weyerhaeuser	-	-	1.1	25

[a] Calculated from mud flow rate and % solids using the following equation:

$$\text{TADP/hr} = \text{Flow rate(gpm)} \times \%\ \text{solids} \times \frac{60\ \text{min}}{\text{hr}} \times \text{solids density} \div \text{lbs mud/TADP}$$

Where: lb mud/TADP = 1000
solids density = 8 lbs/gal.

[b] Calculated from reported lime production rate using the conversion factor of 3.7 TADP/T lime reported in Reference 16.

[c] Calculated from reported grain loading and air flow.

[d] Calculated from reported lime production rate using the conversion factor of 4.1 TADP/T Lime.

Controlled TRS data were obtained from 3 lime kilns. In addition, TRS monitoring data were obtained for 4 lime kilns subject to the NSPS. However, the monitoring data are reported in concentration units (ppm). Design information was available for 4 units which allowed calculation of TRS emissions in terms of lb/TADP, assuming an outlet TRS concentration of 8 ppm, which is the NSPS. Table D lists the design data used for each unit. The following equation was used to calculate TRS emissions in terms of lb/TADP:

$$\text{TRS lb/TADP} = 8\ \text{ppm} \times \text{acfm} \times (1-\%H_2O) \times \frac{\text{std temp}}{\text{actual temp}} \times \frac{1440\ \text{min}}{\text{day}} \times \frac{\text{lb-mole}}{379\ \text{cf}}$$

$$\times \frac{34\ \text{lb}}{\text{lb-mole}} \times \frac{\text{T Lime}}{\text{TADP}} \div \frac{\text{T Lime}}{\text{day}}$$

Table E list the controlled TRS data reported for the 3 compliance tests. The average TRS emission rate for the 7 controlled lime kilns is 0.03 lb/TADP.

7. References

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TABLE D

Mill	Lime Production (T/D)	Conversion Ratio (TADP/TLIME)	Air Flow (acfm)	Temp (°F)	Moisture (% H_2O)	Calculated PM Emissions (lb/TADP)	Reference
Buckeye Cellulose	200	3.8	52,800	400	15	0.04	8
International Paper	240	4.5	58,800	172	35	0.03	29
Union Camp	210	3.7	34,000[b]	-	-	0.05	4
Longview Fibre	1200[c]	-	76,000	330	30	0.03	30

[a] Reference 16.
[b] Scfm.
[c] TADP/day.

TABLE E

Mill	TRS Concentration (ppm)	Air Flow (dscfm)	Lime Production T/D	Conversion Factor (TADP/Lime)	PM Emissions (lb/TADP)	Reference
Hammermill	-	-	-	-	0.01	10
Willamette	5.7	18,830	165	3.7	0.02	16,31
Union Camp	-	-	-	-	0.002	32

APPENDIX D

GLOSSARY OF TERMS

Aerodynamic diameter:	Diameter of a sphere of unit density that reaches the same terminal settling velocity (at low particle Reynolds number in still air) as the actual particle
Black liquor (weak):	A solution of spent white liquor and pulp washwater
Black liquor (strong):	Weak black liquor which has been concentrated in multiple effect evaporators and which received its final concentration in either direct contact or nondirect contact evaporators. The strong black liquor has a solid content of approximately 65 percent.
Cascade impactor:	An inertial based particle collection instrument for determining mass based size fractions
Green liquor:	An aqueous solution of sodium carbonate and sodium sulfide
Inhalable particulate matter:	Particles of respirable size and capable of reaching the lower lung, usually whose diameter is ≤ 15 μm
Kraft pulping:	Pulping where the digestion of wood chips is done with a solution of sodium hydroxide and sodium sulfide
Lignin:	Amorphous polymeric substance related to cellulose that bonds cellulose fibers together
NSSC:	Neutral sulfite semichemical process uses a nearly neutral sulfite solution containing sodium carbonate, sodium bicarbonate, or sodium hydroxide
Oxidation efficiency:	Percentage of sodium sulfide in the black liquor that is oxidized by blowing air or oxygen through the liquor
Pulping:	Conversion of fibrous raw materials into a material which can be converted into paper, paperboard, and building materials

Recovery furnace:	Also called recovery boiler. Unit used to incinerate recovered cooking liquor to produce steam to reprocess cooking chemical.
Recovery furnace (DCE):	A recovery boiler with a direct contact evaporator
Recovery furnace (non-DCE):	A recovery boiler without a direct contact evaporator. Also called a low-odor furnace.
Smelt:	Molten chemicals from the recovery furnace -- mostly sodium carbonate and sulfide
Snow:	Fluffy white particles emitted from an ESP because of reentrainment or overloading
SoRI two-cyclone train:	An inertial based system consisting of two cyclones and a filter in series used for measuring the total particulate concentration, the inhalable particulate concentration and the fine particulate concentration (≤ 2.5 µm)
Soda pulping:	Pulping where the digestion of wood chips is done with a solution of sodium hydroxide
Sulfidity:	In white liquor, the percentage of sodium sulfide to sodium sulfide plus sodium hydroxide where all compounds are expressed as sodium oxide
Sulfite pulping:	Pulping where the digestion of wood chips is done with sulfurous acid, and containing bisulfite of calcium, sodium, magnesium, or ammonia
Weak wash:	Recovered liquor from lime mud washing
White liquor:	An aqueous solution of sodium hydroxide and sodium sulfide

Chemical Symbols

$CaCO_3$	calcium carbonate
CaO	calcium oxide
$Ca(HSO_3)_2$	calcium bisulfite
$Ca(OH)_2$	calcium hydroxide
CH_3OH	methanol
CH_3CH_2OH	ethanol
CH_3COCH_3	acetone
Cl_2	chlorine
ClO_2	chlorine dioxide
CO_2	carbon dioxide
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulfide
H_2SO_3	sulfurous acid
$Mg(HSO_3)_2$	magnesium bisulfite
N_2	nitrogen
Na	sodium
$NaCl$	sodium chloride
Na_2CO_3	sodium carbonate
N_aHCO_3	sodium bicarbonate
$NaHSO_3$	sodium bisulfite
$NaOH$	sodium hydroxide
Na_2S	sodium sulfide
Na_2SO_4	sodium sulfate
$Na_2S_2O_4$	sodium thiosulfate
NH_3	ammonia
NH_4HSO_3	ammonium bisulfite
O_2	oxygen
RSH	methyl mercaptan - CH_3SH
RSR	dimethyl sulfide - $(CH_3)_2S$
RSSR	dimethyl disulfide - $(CH_3)_2S_2$
SO_2	sulfur dioxide